ACIDIC PRECIPITATION IN ONTARIO STUDY (APIOS) ANNUAL PROGRAM REPORT 1988/1989

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INTRODUCTION

In the mid-seventies results from the Ministry of the Environment Sudbury Environmental Study and Lakeshore Capacity Study clearly demonstrated the importance of long range transport of acid rain precursors and the negative impacts of acidic deposition on the environment. In 1979, the Acidic Precipitation in Ontario Study (APIOS) was launched to further study and document the effects of acid deposition, and to implement an effective abatement strategy. Significant human and financial resources have been committed to this program.

The APIOS program has four major components; scientific research, abatement, communications, and litigation.

APIOS operates on a 5-year planning cycle and the second five year plan (1986-1990) is nearing the end. This report gives an overview of the mandates of the APIOS program, accomplishments and major findings in FY 1988/89, and future directions during FY 1989/90.

Ontario's research and emission control efforts are coordinated with other parts of Canada and the United States since the solution to the long range transport of air pollutants (LRTAP) requires action by all jurisdictions. Appendix I provides a summary of international LRTAP projects with MOE involvement. Appendix II provides a bibliography of APIOS related publications and technical reports.

The APIOS program does not have a health effects or materials damage component because these are addressed by small federal specialist groups on a Canada-wide basis. The APIOS Office endeavours to keep abreast of developments in these two areas and ensures that the APIOS technical support is provided when needed (e.g. deposition data).

The scientific research component is divided into six working groups and its programs are developed and implemented under the leadership of work group chairpersons.

Task 1: Atmospheric Processes Studies

Task 2: Aquatic Effects Studies

Task 3: Terrestrial Effects Studies

Task 4: Biogeochemistry Studies

Task 5: Environmental Management and Economics Studies

Task 6: Laboratory Support Services and Methodology Studies

Each program area has its own specific goals and obtains its direction from an interbranch or interministerial working group (the Ministry of Natural Resources contributes to the Terrestrial and Aquatic Effects working groups). In addition, the credibility of the scientific research is assured by a documented and operational quality assurance program.

This report will describe the programs in the six scientific work groups and provide background on abatement, communications and litigation initiatives.

ATMOSPHERIC PROCESSES STUDIES

Contact: M. Lusis

A. EMISSIONS INVENTORY

The compilation of statistics on the production of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and other pollutants serves several purposes:

a. trends in emissions of acid-producing gases are determined and matched with changes in deposition patterns;

b. detailed information on SO_2 and NO_x emissions by geographic location is required by all of the atmospheric models;

c. knowledge of the location and magnitude of emission sources is also essential in planning cutbacks of acid gas emissions.

The Ontario Acid Rain Emission Inventory was upgraded during FY 1988/89 to provide more complete information regarding SO_2, NO_x and VOC (volatile organic compound) emissions as well as related statistics. The 1985 base year Ontario emission inventories for SO_2, NO_x and VOC have now been finalized (in cooperation with Environment Canada), and summaries are shown in Figures 1 to 3. A detailed study on some of Ontario's major SO_2 emitters was conducted in July and August 1988. Results of this study provide valuable input to long range transport models. Emission inventories for alkaline dust, ammonia and trace metals such as cadmium, arsenic, iron and manganese were also compiled (see Figures 4, 5 and 6).

Methodology for NO_x and VOC has been upgraded by the use of a model (MOBILE 3) for emissions for mobile sources. Raw data and emissions estimation methods were also established together with Environment Canada for area sources.

Trend analysis of the preliminary 1986 and 1987 data shows an 11% increase in total emissions of SO_2 between 1983-1987. This trend reflects the general economic recovery in the province since 1983. Overall, however, there was a decrease in SO_2 emissions from 1980 to 1987 of about 20%, from 1.8 million tonnes to 1.4 million tonnes. NO_x emissions increased slightly from 1980 to 1987. Vehicles account for about half of the total NO_x emissions (Figure 7).

B. MODELLING STUDIES

One of the primary goals of the Acid Rain program is to establish source - receptor relationships, i.e., to determine the degree to which a receptor is affected by major emission source areas in North America.

Mathematical models combine our knowledge of the movement of air masses and the scavenging and chemical transformation of pollutants during transport into a

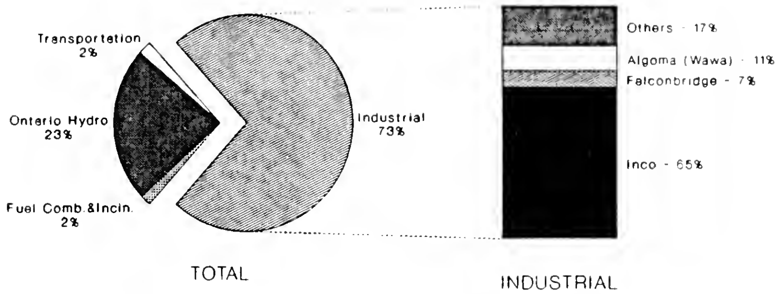


Figure 1. 1985 SO_2 emissions in Ontario.
Total = 1,457 kilotonnes.

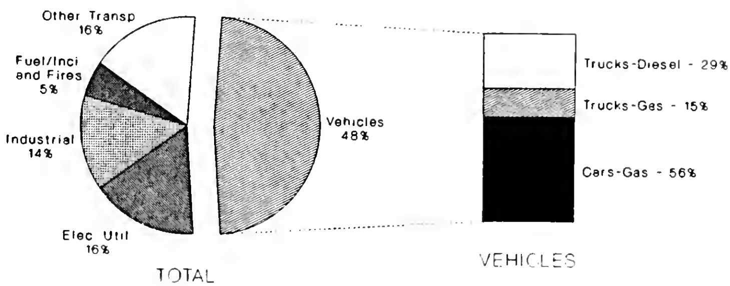


Figure 2. 1985 NO_x emissions in Ontario.
Total = 585 kilotonnes.

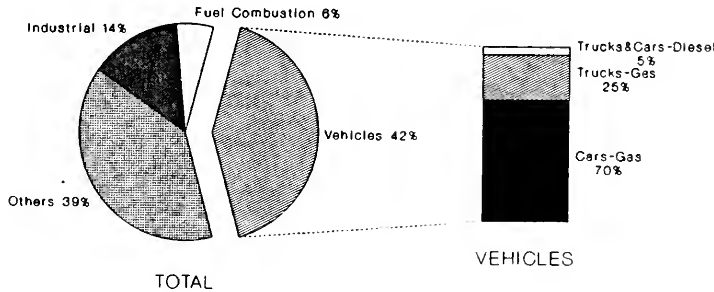


Figure 3. 1985 VOC emissions in Ontario.
Total = 620.7 kilotonnes.

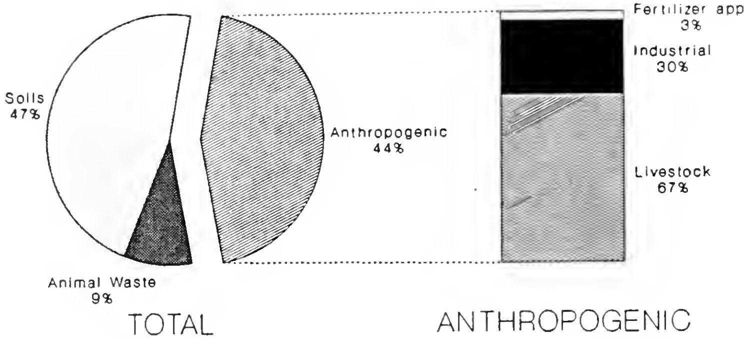


Figure 4. 1985 ammonia emissions in Ontario.
Total = 113.8 kilotonnes.

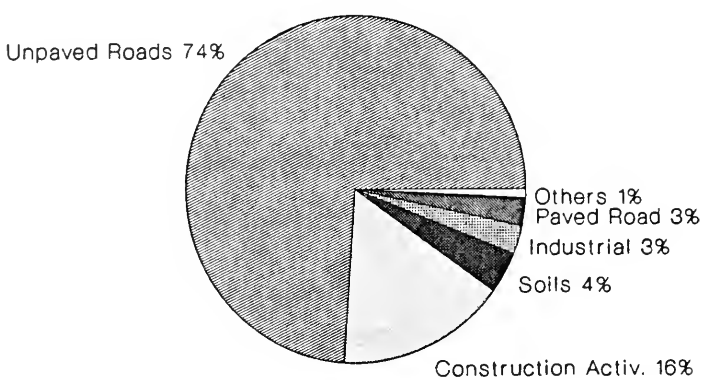


Figure 5. 1985 Alkaline dust emissions in Ontario.
Total = 1,572.7 kilotonnes.

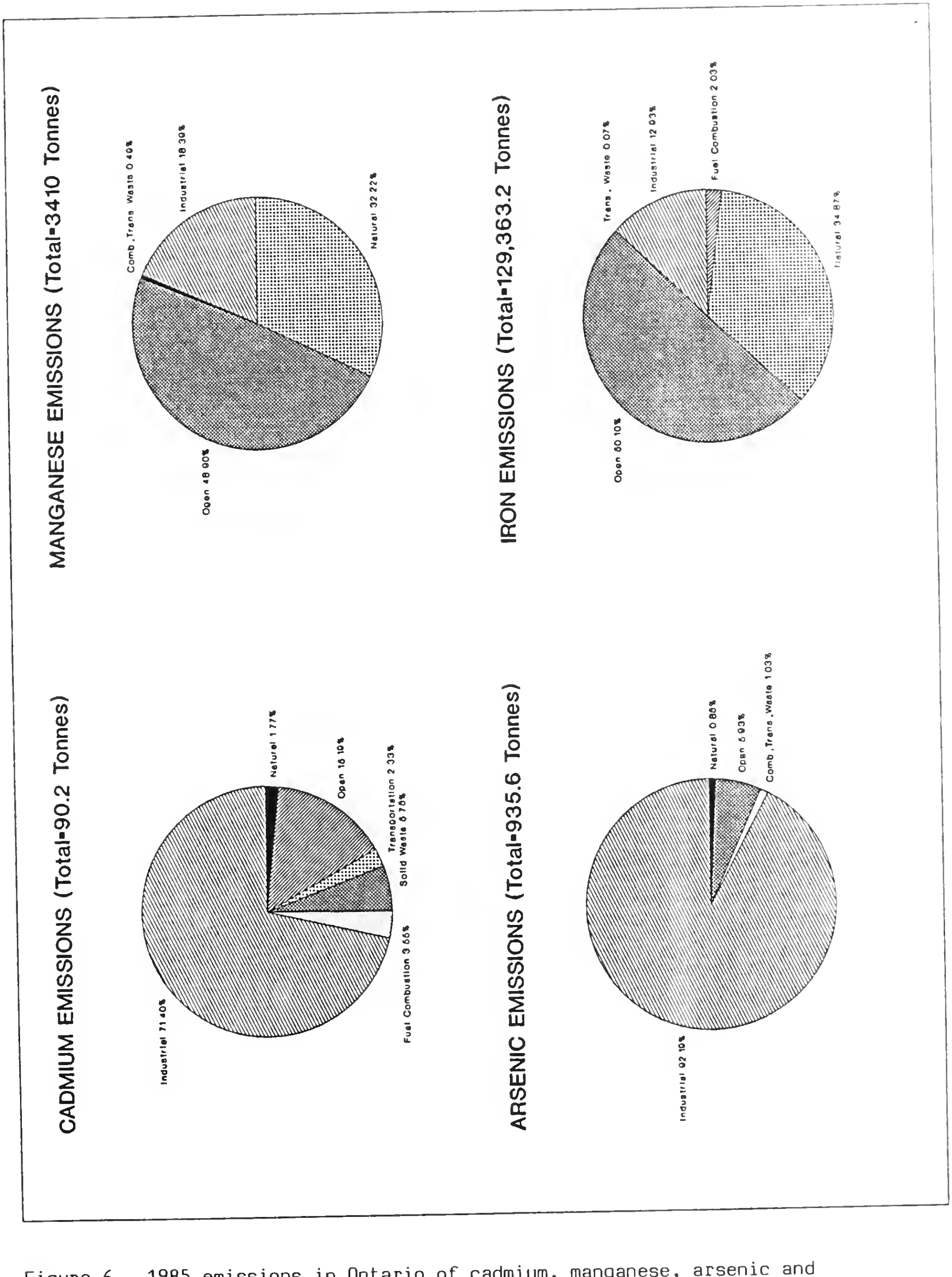
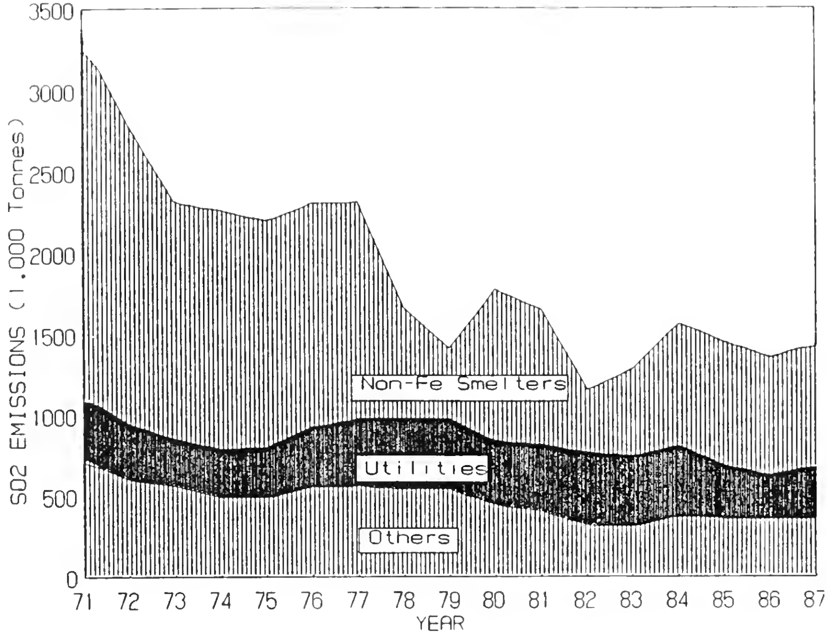


Figure 6. 1985 emissions in Ontario of cadmium, manganese, arsenic and iron.

(A)



(B)

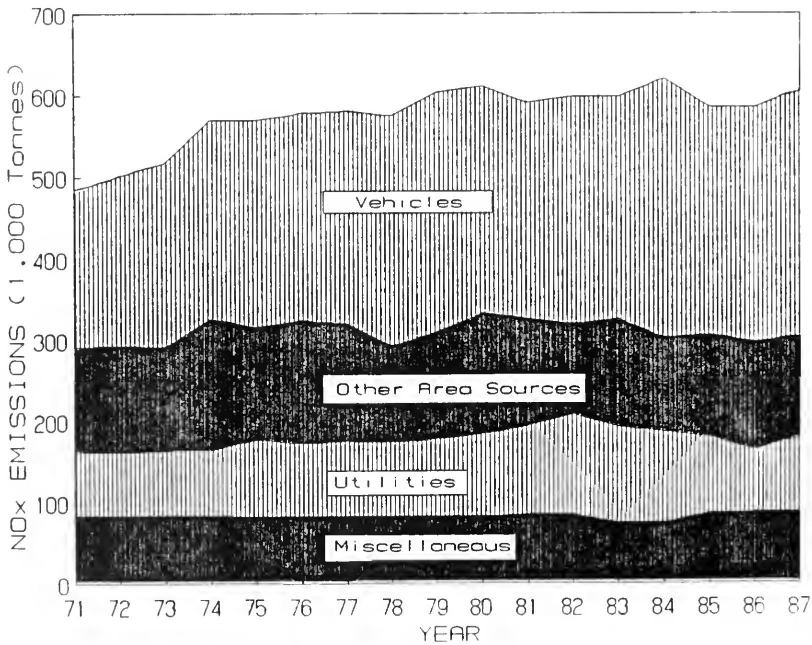


Figure 7. 1971-1987 Ontario total SO_2 emission trend (A) and NO_x emission trend (B).

set of numerical equations. Output from the models can be compared to observed deposition patterns, and if the comparison shows a close agreement, we gain confidence that we have a good understanding of the causes and mechanisms involved in acid deposition. Once the models are sufficiently developed, emission reduction scenarios can be assessed by looking at resulting deposition patterns.

The models can also be used for the interpretation of data. For instance, because of meteorological variability the deposition of acidic pollutants at a receptor can undergo large fluctuations on an annual basis. This poses a problem in determining the effects of an emission control scenario using the observed data at a receptor. A properly validated model allows us to screen the meteorological variability out so that the expected change in the deposition at a receptor from a given emission control can be evaluated.

Several models have been developed and evaluated towards this end.

The Acid Deposition and Oxidant Eulerian Model (ADOM) was evaluated for 20 days in April, 1981, coincident with the OSCAR field study (Oxidation and Scavenging Characteristics of April Rain). Several sensitivity tests of the model were also performed. These results were reported in the FY 87/88 annual report. They have since been repeated with a new cloud module. The conclusions have not changed with these new simulations; the predicted and modelled sulphate concentrations in precipitation generally agree within a factor of two.

The Eulerian model will be evaluated again in the next two years with data obtained in the joint U.S. and Canada field study project (See Section C below). The study is expected to provide detailed information on many chemical species which the model uses in input and generates as output.

The transport module of ADOM has been evaluated against data from ANATEX (Across North America Tracer Experiment). In ANATEX, non-reactive tracers were released at two locations (Minnesota and Montana) and monitored at arcs away from the release points. The spatial resolution of the monitoring network was 3-400 km. Tracer releases took place over a 90-day period in the winter of 1987.

Figure 8 shows a long term average (45 days) of the modelled and observed tracer concentrations. The observed pattern is limited by the location and the spatial resolution of the monitors.

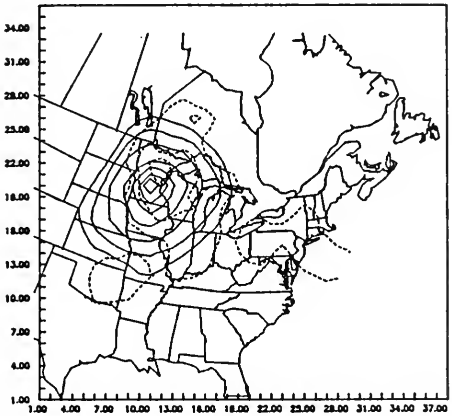


Figure 8. 45-day averaged pattern for the tracer PDCH released from St. Cloud, Minnesota during January 5 - February 17, 1987. The solid lines are the modelled pattern while dashed lines show the observed pattern. The units are in femtolitre tracer/litre of air (fl/l) and the values of the contour, starting with the outermost are 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0 and 100.00.

ADOM has also been evaluated for a 9-day, high-ozone episode in June 1983. For this study, a biogenic reactive hydrocarbon emission inventory was developed and added to the input data. Model results were compared with observed hourly ozone concentrations at about 30 stations in Ontario and the northeastern United States. Comparisons of observed and modelled time series indicate that the model is properly simulating both the diurnal pattern and the maximum ozone concentrations. When daily observed maxima at the stations were compared with model results the bias was very small and the geometric standard deviation was 1.4 (i.e., more than 95% of the predictions were within a factor of two of the observations).

This data set was then used to investigate the effects of NO_x and VOC emission reductions on ozone concentrations in Ontario. The conclusions were:

1. NO_x was the limiting pollutant for ozone production during this episode.

2. Due to outside sources Ontario would be unable to prevent ozone levels exceeding 80 ppb even if Ontario NO_x emissions were eliminated.

C. DEPOSITION MONITORING NETWORK

The daily and cumulative (28 day) networks were used to monitor deposition in the province through 1988. Data from the daily network forms an important component of the Eulerian Model Evaluation Field Study (EMEFS) which started in June 1988, and is scheduled to run for two years. EMEFS is a cooperative venture between the Ontario Ministry of the Environment, Environment Canada, the US EPA, the Electric Power Research Institute, and the Florida Acidic Deposition Monitoring Program.

There was intensive monitoring from July 15 to August 31, 1988 as part of EMEFS. During this time a number of chemical species, including formaldehyde, hydrogen peroxide, ozone, sulphur dioxide and sulphate aerosols were measured at Dorset. Figures 9 and 10 show the six-hour average concentration of sulphur dioxide and sulphate and clearly indicate the pollution episodes (day zero in these plots was July 17, 1988). Some sample results for formaldehyde and hydrogen peroxide levels in air at Dorset, measured by a tunable diode laser absorption spectrometer on August 16, 1988, are shown in Figures 11 and 12. Similar measurements were made at Environment Canada's Egbert and Borden sites, and on board two aircraft flying between the three sites.

Results from the APIOS cumulative monitoring stations located in the Great Lakes Basin were used to assess trace metal deposition to the Great Lakes. Figures 13 and 14 show results for lead.

The provincial APIOS network data were also updated with new results, to better determine long-term loadings of acidic substances in Ontario. Figures 15 and 16 show average annual wet and dry sulphate deposition (the dry sulphate deposition includes the contribution from both sulphur-bearing particulate matter and gaseous SO_2), based on measurements during the 1981-1986 period.

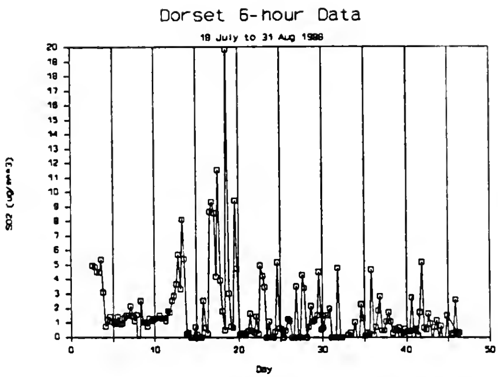


Figure 9. Six hour average concentration of SO_2 in air at Dorset, July 17 to August 31, 1988.

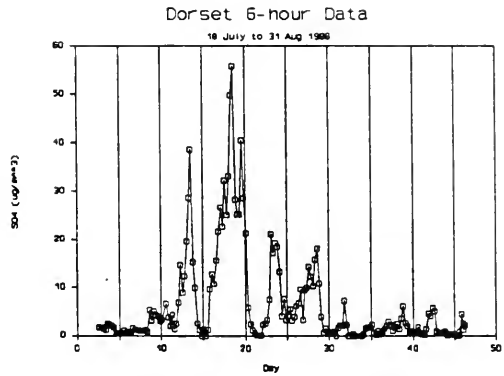


Figure 10. Six hour average concentration of SO_4 in air at Dorset, July 17 to August 31, 1988.

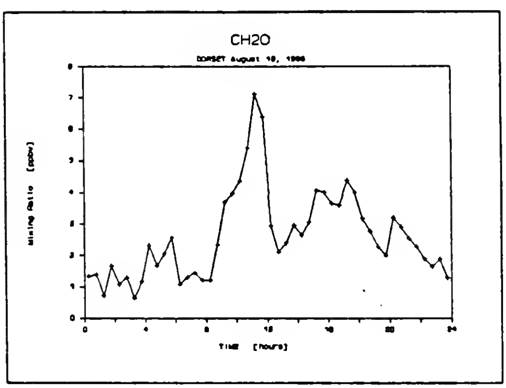


Figure 11. Measurement of formaldehyde in air at Dorset, August 16, 1988.

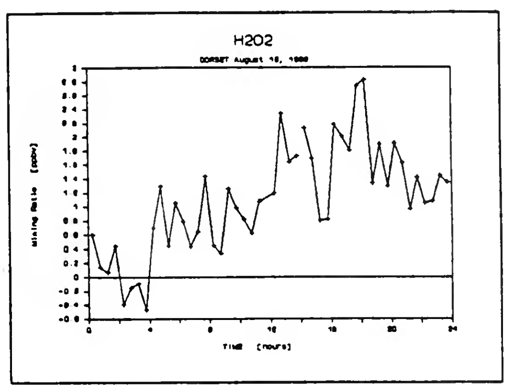


Figure 12. Measurement of hydrogen peroxide in air at Dorset, August 16, 1988.

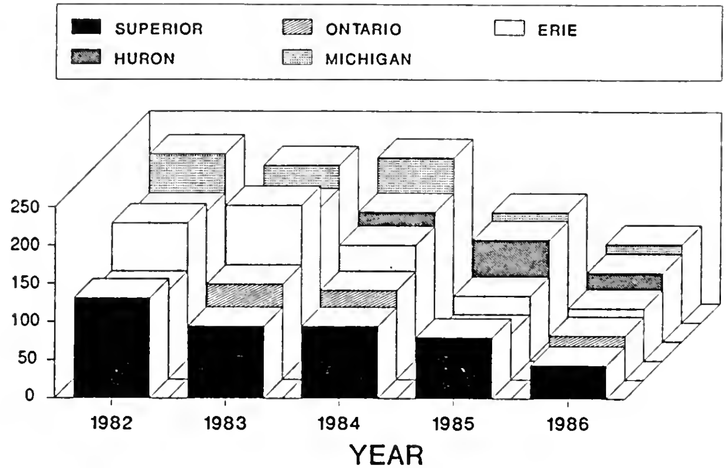


Figure 13. Dry deposition of lead (1000 kg) into Great Lakes.

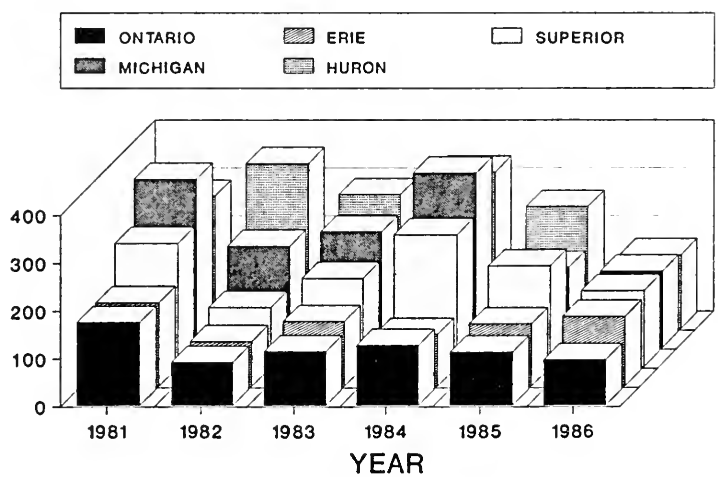


Figure 14. Wet deposition of lead (1000 kg) into Great Lakes.

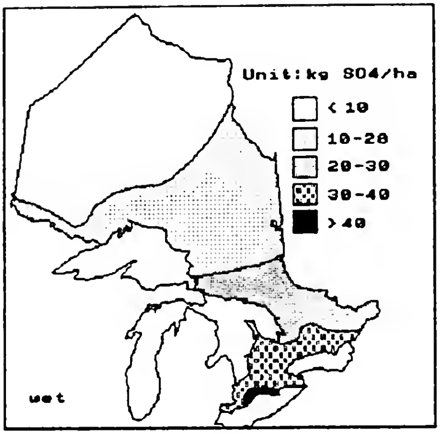


Figure 15. Annual SO_4 wet deposition in Ontario (average for 1981-1986).

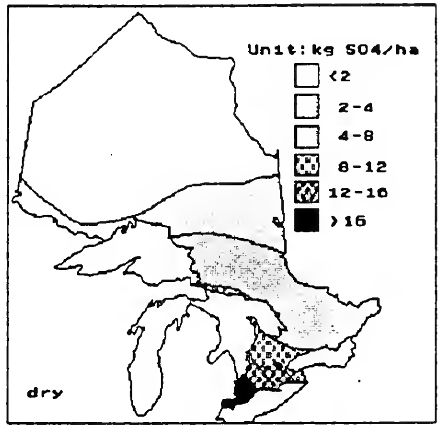


Figure 16. Annual SO_4 dry deposition in Ontario (average for 1981-1986).

D. OXIDANTS STRATEGY DEVELOPMENT

ADOM (the Atmospheric Deposition and Oxidant Model) was used to assess the relative contribution of hydrocarbons and nitrogen oxides to ambient oxidant levels in Ontario. These runs, already referred to in Section B, suggested that control of local nitrogen oxide emissions would be more effective than hydrocarbon emissions control for lowering oxidant levels. Also, most of the oxidant burden in Ontario was attributed to emissions in the United States. A further analysis of the extensive Ontario data during the 1984 Sarnia Oxidant Study confirmed the above conclusions.

The cost of hydrocarbon and nitrogen oxide emission controls for point sources in two industrial areas - Sarnia and the Hamilton-Toronto-Oshawa metropolitan area was assessed, for various control scenarios. The various scenarios and costs are discussed in the Environmental Management and Economics section.

A draft oxidant control strategy document was prepared, which recommends that (bearing in mind the relatively minor contribution to oxidant levels in Ontario due to local sources, and the substantial costs of control), the provincial government take no additional steps beyond the initiatives already being considered to control oxidant precursor emissions. These initiatives include substantial reductions in hydrocarbons and nitrogen oxide emissions due to revisions in Regulation 308 of the Environmental Protection Act, the adoption of California tailpipe emission standards for light duty vehicles, and a more rigorous vehicle inspection program.

E. METEOROLOGICAL STUDIES

A meteorological data acquisition system (MDAS), capable of providing support for special studies and episode analysis, as well as modelling activities, has been implemented. MDAS is a computerized system which collects and stores meteorological data supplied by

Environment Canada from the North American network of weather stations. Air parcel trajectories are also calculated by the system for interpreting event precipitation and other air quality data.

During FY 1988/89 meteorological data were acquired and archived on an on-going basis. Air parcel trajectories at various locations in Ontario and eastern North America were calculated and archived on a daily basis. As well, the daily synoptic weather patterns for various locations in Ontario were also categorized and archived. Residence time analyses during transport were also completed.

Plans to have a satellite link via the Anikom 100 service to receive the meteorological data from Environment Canada are now actively under development.

A meteorological study was published in 1988 concerning the contribution of local and U.S. sources to oxidant levels in southern Ontario. The study found that more than half of the elevated ozone levels in Southern Ontario can be attributed to percursor emissions in the United States.

Other data analysis dealt with trends in sulfate and nitrate deposition in the Muskoka area. The decrease in emissions of SO_2 in eastern North America in the past decade was strongly correlated with a decrease in bulk deposition rates and concentrations of sulphate and hydrogen ions in precipitation in central Ontario. Nitrate emissions, deposition and concentrations have not changed significantly over the same period.

TERRESTRIAL EFFECTS STUDIES

Contact: W. McIlveen

The primary objective of the Terrestrial Effects program is to determine the impact (if any) of acidic precipitation and related pollutants on the terrestrial environment. The program is divided into three sub tasks: Vegetation, Soils, and Forest Productivity and Decline studies (responsibility of the Ministry of the Environment), and the Wildlife sub task (responsibility of the Ministry of Natural Resources). All of these sub tasks include several component projects.

A. VEGETATION STUDIES

Mobile Rain Exclusion Canopies

A fully-automated rain exclusion canopy (REC) located at the MOE Phytotoxicology Laboratory in Brampton is used to assess the impact of acidic deposition and ozone on commercially valuable forest trees. The system consists of three mobile greenhouse shelters which exclude ambient rainfall and apply simulated acid rain (SAR) treatments to test plants established in the field. All aspects of the set-up are controlled by a microcomputer and data acquisition system. Depending on the research objectives, ambient levels of gaseous pollutants (i.e. O_3, SO_2 and NO_x) can be reduced in the field plots via a filtering system and perforated polyethylene distribution tubes. Gaseous pollutants such as ozone can also be injected into the treatment plots.

a. Soybean Studies

The REC system was used in 1985 and 1986 to investigate the impact of acidic precipitation on yield of soybeans (Glycine max cv. Hodgson). Treatment effects were determined for various components of yield; i.e., seed yield (kg/ha), pod number per plant, seed number per pod, seed weight (g/100 seeds), and plant height. Results of the 1985 field study suggest that increased acid content of SAR had a slight stimulatory effect on soybean yield. For each of five SAR treatments, soybean yield (kg/ha) obtained in 1985 was significantly greater than the 1986 yield. The yield results can be attributed to differences in seed weight caused by environmental conditions specific to the two growing seasons. The acid rain treatments did not produce a yield effect in 1986.

b. Forest Tree Species Studies

The REC system is presently being used to study the effect of acidic deposition on sugar maples, white spruce and poplar. During the fall of 1985 and spring of 1986, sugar maple transplants from the Dorset area and nursery-grown white spruce seedlings were potted in mineral soil taken from a site near Dorset (the Leslie Frost Centre). The most

vigorous individuals were used for experimentation under the REC system commencing in the spring of 1987. Rooted cuttings of three clones of hybrid poplar were also planted under the REC system to provide shelter for the maples and serve as an additional species to monitor.

The trees were subjected to three different SAR treatments (pH 3.2, 4.3 or 5.6) at regular intervals. Non-destructive measurements on the seedlings include:

1. visible injury rating;

2. photosynthesis rates;

3. throughfall and soil leachate chemistry;

4. plant height, stem diameter, leaf number.

Destructive sampling of selected seedlings will be made to investigate:

1. pigment content of leaf tissues;

2. physical and chemical changes in roots and foliage;

3. mycorrhizae.

Results are expected in 1990.

Insect - Acidic Precipitation

Much of the more severe dieback of sugar maple in Ontario is associated with defoliation by forest tent caterpillars. Since there is a possible interaction of acidic precipitation with insect defoliation (i.e., acid stressed trees may be preferred hosts of the insect), this possibility is being investigated. Potted sugar maples are subjected to simulated acid rain at two pH's. They are then defoliated to different degrees either mechanically or by controlled insect feeding. The trees are monitored for growth and survival. The preference of the insects for foliage subjected to different acid treatments and the growth rates of the insects on these diets is being examined. The first year of the two-year project has been completed. The limited data presently available showed reduced growth of the tree seedlings following both severe mechanical and insect feeding defoliation. Further experimentation is necessary before conclusions on the interaction of the insects with acid treatments can be reported.

B. SOIL STUDIES

Concentrations of Metals in Surface Soils

Surface soil concentrations of nickel, copper, lead, and zinc determined for 300 undisturbed soils across southern and northeastern Ontario (1980-1984) were mapped using the Meteorological Data Acquisition System contour mapping program. The results show that high surface concentrations of nickel and copper centred on Sudbury completely dominate the distribution pattern of these two metals (Figure 17).

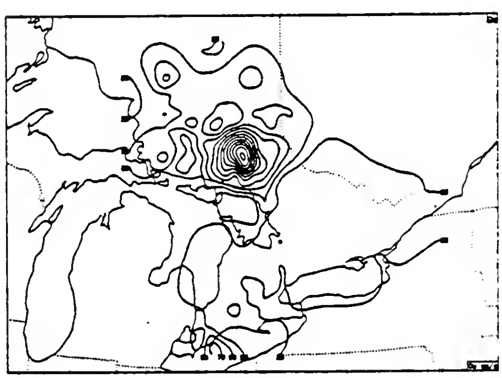


Figure 17. Distribution of copper in surface soils in Ontario.

Surface soil lead concentrations are generally higher in the southern portion of northeastern Ontario than in southern Ontario, but the lead contour maps do not display the degree of dominance of Sudbury evident for copper and nickel.

In the northeast, there are two areas where zinc concentrations are high, one north of Elliot Lake, the other near Ranger Lake. These areas are coincident with recent forest fires, and the sampled sites had a predominance of birch and poplar, known accumulators of zinc. Hence these high zinc levels in surface soils in the north may be the result of a combination of forest fire action and biogeochemical cycling by tree species. In the south, high zinc levels exist throughout the soil profile, and are therefore likely a reflection of parent materials.

Sources of Variability in Soil Properties

This study addresses spatial and temporal variability of soil properties and considers implications for soil baseline monitoring.

One site at Harp Lake and another at Plastic Lake near Dorset were sampled on a one metre grid with 33 sample points per site. Samples were collected in the spring, summer, and fall of 1982 and 1983 in order to detect seasonal and yearly variations in 23 soil parameters. Preliminary results show a wide variability in soil properties, with overall coefficients of variation (c.v.) ranging from 95% for dithionite extractable manganese to only 6% for pH. The low variability for pH is clearly a result of its definition because pH is a logarithmic measure of hydrogen ion concentration; the latter property has a c.v. of 56%.

Figure 18 shows the extent of spatial variability encountered for exchangeable magnesium across the A horizon (upper surface) and the B horizon (lower surface) of a 10 m grid at Harp Lake. This graph demonstrates the difficulties that are encountered in attempting to quantify a soil property at one site and utilizing this information to determine if there are changes over time. For baseline monitoring studies, it will be necessary to group sites according to both soil sensitivity to acidic inputs and deposition gradients in order to be able to detect any changes.

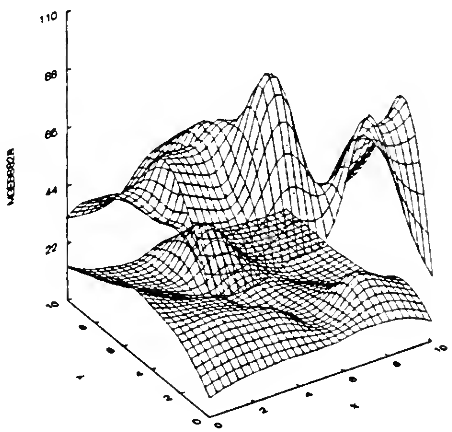


Figure 18. Spatial distribution of magnesium in two soil horizons (A and B) at Harp Lake, August, 1982.

Figure 19 is an estimate of the number of sites that would have to be grouped together in order to obtain a given level of accuracy with 80% confidence for four of the measured parameters (soluble aluminum, clay content, total copper, and pH in water extract).

Preliminary results also indicate considerable differences in variability and property means

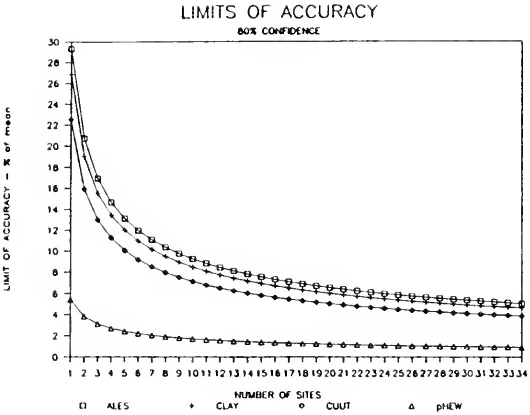


Figure 19. Number of sights needed to be grouped together to obtain level of accuracy (80% confidence).

between horizons and emphasize the need for sampling to occur by horizon rather than by depth. Improvement in reducing sample variability could be achieved by pooling samples obtained from a much larger area than can be obtained from a soil pit (i.e. by using a soil corer).

Nine of the measured properties showed statistically significant changes in mean values by year. Many of these properties, such as clay content, silt content and organic carbon, would not be expected to show any noticeable change in a short time. The apparent increase in silt content from 1982 to 1983 may be due to an increase in dithionite extractable iron and aluminum and the binding of clay sized particles into silt sized particles. However, no natural physical process could explain the large increase in organic matter content in one year, hence, the yearly changes observed in these properties may be a result of the intensive sampling procedure itself, in conjunction with normal soil forming processes, creating altered conditions in the second year. A dilemma is thus created; if one is to sample intensively enough to properly characterize the spatial variability, there is a possibility that the sampling could affect subsequent measurements and bias estimates of temporal variability.

Five parameters showed significant decreases in c.v. from 1982 to 1983. All were metals, and all but one (zinc) exist in more than one valence state. Since 1982 was a very cold and wet year (coldest since 1929), reducing environments would have existed for much longer in 1982 than in 1983. Reduced forms of metals are more mobile than their oxidized counterparts and hence increased variability could be expected in 1982. Detection of these changes over a one year period was unexpected.

Nine parameters showed significant seasonal changes. The observed increase in nitrogen content of the A horizon in the fall can be explained as a result of biological activity and leaching from leaf fall. The seasonal decrease in sand content is equivalent to the seasonal increase of silt plus clay. The explanation provided above (changes in dithionite extractable iron and aluminum fractions and larger particle size) is less plausible seasonally than yearly. Although the appropriate pattern of change exists, it is unlikely for 'glueing' materials to be sufficiently strong to hold silt and clay sized particles together as sand sized particles against the forces existing during the analyses. Observed seasonal variations in total copper and nickel concentrations are also not readily explainable.

The variability of extractable (pyrophosphate, dithionite, and calcium chloride) forms of aluminum increased in the summer and decreased considerably in the fall. It is of interest that these aluminum measurements, which are of

primary concern in terrestrial effects studies, are most variable in the season in which they are most likely to be monitored.

C. FOREST PRODUCTIVITY AND DECLINE STUDIES

Maple Decline Study

This study was initiated in 1984 to determine the role of acidic deposition in the decline of woodlots managed for maple syrup production in the Muskoka/Haliburton area of Ontario. Permanent observation plots were established to assess tree condition at seven locations. A control site at Thunder Bay was established in an area of low acidic deposition. In 1985, additional plots were added on calcareous soils near Peterborough and in an unmanaged stand in Algonquin Provincial Park. Tree condition has been assessed annually since the plots were established.

In general, the condition of the trees remained the same or possibly improved slightly from 1984 to 1987. In 1988, however, the degree of decline in the two Southern Ontario areas was the highest of any year measured (Table 1). The primary reason for the higher decline index was an increase in the degree of yellowing of foliage, partially attributable to the drought conditions which prevailed in 1988 and, in some cases, to the effects of insect defoliation.

Determining the cause of tree dieback at each site is difficult owing to the many stresses that are or were in effect prior to the dieback. Severe defoliation by forest tent caterpillars in Muskoka in the late 1970's was combined with spring droughts in 1976, 1977 and 1983. Armillaria root rot, tree age, site management and possibly the additional stress of acidic deposition, may be responsible for the observed poor tree condition since 1984. Extremes in weather conditions also have a role to play. Defoliation of the trees at some plots occurred in 1987 and 1988 and is anticipated to occur again in 1989.

Table 1: Annual variation in tree condition assessment at the 11 study plots; 1984 to 1988

	Mean Decline Index*				
Plot	1984	1985	1986	1987	1988
Muskoka Mean	22.5	20.9	22.2	18.3	31.2
Peter-borough Mean		16.6	14.2	11.2	17.4
Thunder Bay Mean	18.6	18.4	27.6	15.4	17.3

* Decline index from 0 - 100, ranges are approximation:

0-15 healthy
16-30 moderate
greater than 30 severe

Hardwood Decline Studies

In FY 1985/86 and FY 1986/87, a study was initiated to determine the incidence and severity of hardwood decline across the province. One hundred and ten permanent observation plots dominated by sugar maple were established across the province. Each tree within the plot was assessed according to the amount of dead branches, chlorosis and undersized leaves in the crown. The data was used to calculate a decline index using 0 to represent a tree without any dieback and 100 to represent a dead tree. Data from the original evaluation show plots with moderate to severe dieback in the south-western part of the

province as well as the Niagara and Muskoka areas. Dieback is scattered through the northern part of the study area while there is a broad band of relatively healthy hardwood stands extending from Lake Huron south of Georgian Bay east to the Ottawa area. No pattern of dieback was seen that could be directly related to acidic precipitation patterns; however, soil characteristics, particularly higher buffering potential of limestone-based soils, may have an important role in the distribution of the problem sites. The severity and extent of dieback was greatest where soil was most sensitive and deposition was highest.

In 1987, the plots were re-examined to determine whether the condition of the trees as measured by the Decline Index had changed. The 1987 survey identified plots in the regions of Algonquin, Parry Sound, Muskoka, Niagara, London, Cornwall and the north shore of Lake Huron where the Decline Index was higher then in 1986. These areas correspond to known or suspected forest insect infestations. For the majority of the plots not affected by defoliating insects, the mean Decline Index of trees did not change by more than one standard deviation between 1986 and 1987. There was no evidence of a relationship between tree decline and wet sulphate deposition patterns. Changes in decline indices from 1986 to 1987 are shown in Figure 20.

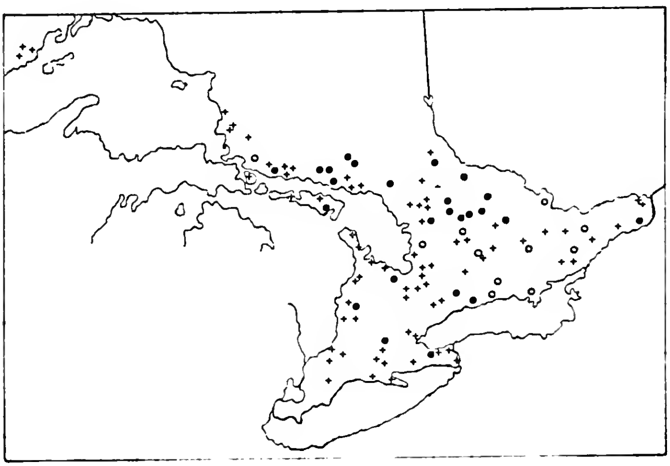


Figure 20. Changes in sugar maple decline indices from 1986 to 1987 for Hardwood Decline Survey plots in Ontario.

Changes in Decline Index
- o decrease > 5.4 (1 S.D.)
- + little change < 1 S.D.
- • increase > 5.4 (1 S.D.)

Hardwood Nutrition Studies

A potential effect of acidic precipitation is the leaching of plant nutrients from the soil. This could result in reduced plant growth and be reflected in the foliar chemistry of vegetation growing on the site. In 1986 and 1987 foliage and soil chemistry was studied for two tree species; yellow birch (*Betula alleghaniensis*) and sugar maple (*Acer saccharum*). The intent of the sampling was to identify relationships between foliage and soil chemical properties and to relate these to the condition of the trees at the sites.

The results of this study, which included 35 of the Hardwood Decline Study sites for each species across Ontario, indicated that there were no marked nutrient imbalances or deficiencies in the foliage or the soil.

A summary of the average mineral element content in the foliage of each species is shown in Table 2. Aluminum which is mobilized following acidification of soil was found to be highest in sugar maple foliage collected at sites within the zone of highest deposition of sulphate in the Province (Figure 21).

Table 2: Summary of the overall average, minimum and maximum levels of nutrients and other elements in the sugar maple and yellow birch foliage samples.

FOLIAGE ELEMENT	SUGAR MAPLE MEAN	MIN	MAX	STANDARD DEVIATION	YELLOW BIRCH MEAN	MIN	MAX	STANDARD DEVIATION
MACRONUTRIENTS								
N (%)	1.98	1.42	2.50	0.40	2.55	2.00	3.04	0.35
P (%)	0.17	0.10	0.31	0.07	0.18	0.11	0.31	0.05
K (%)	0.84	0.58	1.33	0.18	1.13	0.65	1.61	0.31
Ca (%)	1.32	0.72	1.92	0.36	1.40	0.95	2.66	0.42
Mg (%)	0.19	0.11	0.38	0.07	0.28	0.17	0.41	0.07
S (%)	0.20	0.15	0.25	0.03	0.14	0.12	0.17	0.02
MACRONUTRIENTS								
Cu (ppm)	5.4	3.6	7.3	1.3	6.3	4.3	7.9	1.1
Fe (ppm)	84	39	208	79	98	66	208	36
Mn (ppm)	755	82	2280	702	1717	203	5480	1276
Na (ppm)	11.7	10.0	19.0	3.2	14.1	6.0	38.2	7.7
Zn (ppm)	23.0	13.0	48.4	9.8	334.2	100.0	486.0	132.4
OTHER ELEMENTS								
Al (ppm)	47	20	150	33	54	22	144	33
Cd (ppm)	0.28	0.05	0.52	0.16	2.51	0.56	3.68	1.04
Cl (%)	0.06	0.02	0.12	0.03	0.01	0.01	0.06	0.01
Mo (ppm)	0.33	0.25	0.90	0.09	0.48	0.25	0.80	0.08
Ni (ppm)	1.44	0.50	6.24	1.22	2.65	1.00	5.76	1.59
Pb (ppm)	1.55	0.50	2.80	1.13	2.26	1.00	4.26	0.88

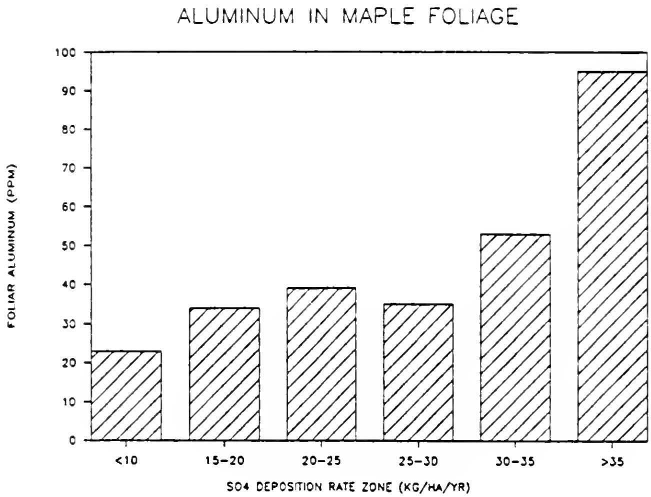


Figure 21. Aluminum in maple foliage sampled from six SO_4 deposition zones.

Soil pH was the soil parameter which was most consistently correlated with foliar element concentrations. Foliage of both species contained lower concentrations of calcium and magnesium and higher concentrations of manganese, copper and zinc when associated with lower soil pH.

Higher Decline Index ratings were associated with lower soil pH and higher foliar manganese. Further interpretation of the data is warranted and can be used as baseline data for future sampling efforts.

The nutritional studies also serve as a basis for mitigative investigations. In a number of locations including Europe and Quebec, considerable resources are expended in an attempt to reverse the progress of tree dieback through the application of plant nutrients or limestone. A great deal of information is required before accurate treatment recommendations can be made about the application of these materials. In 1988, a fertilizer application trial was set up in cooperation with the Ontario Maple Syrup Producers Association. The trial involved four sites, each with trees in two classes of decline (moderate decline and relatively healthy). Treatments included individual nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, lime) and combinations of nutrients in addition to the control. The foliage and soil were sampled prior to treatment to document the nutrient status of each tree. Trees will be monitored to determine if the treatments bring about improved health and nutrient status in future years.

Remote Sensing

Rapid assessment of the extent and severity of forest dieback relies on techniques with a remote

sensing component. Such techniques are expensive and are still in the developmental stages. In 1988, a relatively inexpensive remote sensing approach was used to study sugar maple dieback. By combing light filters and a series of video cameras it was possible to obtain photographic records of selected maple plots. The video tapes were digitally analysed using a computer. Initially, the method appears to be highly promising but a final report is pending.

D. MNR WILDLIFE STUDIES

Cadmium Accumulation by Aquatic Plants Preferred as Forage by Ontario Moose.

In Ontario, the highest cadmium levels in the tissues of moose and deer have been found in populations from areas of poorly-buffered and acid sensitive soil. Higher levels have been found in moose than deer. This may be due to the aquatic feeding habits of moose, since many freshwater aquatic plants are known to be highly effective bioaccumulators of metals. Two hypotheses were tested regarding cadmium content in aquatic plants:

a. cadmium levels of plants with poorly buffered soil do not differ from levels in areas of well buffered soil;

b. species of aquatic plants favoured by moose do not differ in cadmium content from species less favoured by moose.

These species of aquatic plants were chosen for sampling according to moose palatability: Utricularia vulgaris, Potamogeton gramineus, and Nymphaes odorata. The first two are highly palatable while the third is unpalatable. Cadmium levels in aquatic plants in Algonquin Park, a poorly-buffered acid-sensitive area were significantly higher than those from Cornwall, a well-buffered, acid insensitive site. Moreover, the two species tested that were highly preferred by moose had higher levels of cadmium than did the unpalatable species.

BIOGEOCHEMISTRY STUDIES

Contact: P. Dillon

A. BIOGEOCHEMICAL STUDY SITES - MONITORING PROGRAMS

The biogeochemistry studies provide baseline data about the physical, chemical and biological state of the watersheds. The study results will help to determine the changes that occur over time with continuing acid rain.

The APIOS program has established watershed study areas near Dorset (south-central Ontario) and near Thunder Bay (northwestern Ontario). The study catchments located at Plastic and Harp Lakes in south-central Ontario are in a high sulphur deposition area. The Hawkeye Lake site in northwestern Ontario is in a low sulphate loading area.

All three sites lie on the Precambrian Shield, the location of most of Ontario's productive forest land. The Shield represents the area most sensitive to acidification and includes prime wilderness and recreational resources.

These intensive 'biogeochemical' studies focus on the chemistry of an entire catchment and emphasize the links between land and water systems. Inputs of rain and snow undergo changes as they pass through the forest canopy, through the forest floor and underlying soil, and finally as they emerge as streamflow discharged from the watershed.

The Plastic Lake site has shallow soils with mainly coniferous trees. The Harp Lake site has deeper soils with mainly deciduous trees. The Hawkeye Lake site has soils ranging in depth from very shallow to over 20 m, with a mixed forest stand.

Routine sampling occurs at all three sites. Bulk samplers monitor precipitation quantity and quality. Weirs are used to monitor water quantity in the streams draining the study areas, and lysimeters collect the water percolating through the soil.

Lysimeter (soil water) data for subcatchments of Plastic and Harp Lakes were used to assess the alkalinity generation in the soils of the two catchments.

Plastic soil water had lower alkalinity than that of the Harp soil water because of higher sulphate concentrations. To a typical litre of rainwater percolating through the catchment, upland soils in the Harp Lake catchment add 31 ueq of alkalinity whereas Plastic upland soils add 23 ueq alkalinity. The difference in alkalinity generation is not due to differences in base cation release (138 vs. 139 ueq), but to increased strong acid anion release (143 vs. 82 ueq of sulphate) which

is only partly balanced by increased aluminum dissolution (22 vs. 1 ueq) in the mineral (B) horizons of the Plastic upland soils.

Base cations are released from different areas in the soil profile in Harp and Plastic upland soils. In Harp, larger amounts are released in the top organic layer (LFH) causing increased pH and alkalinity there. It is not until the water reaches the lower mineral layers in Plastic upland soils that the base cation levels reach those of Harp.

Conversely Plastic LFH layers release larger amounts of organic acids than Harp, however these are almost completely adsorbed in the lower mineral layers of both catchments and there is little resulting differences in the water draining them. Consequently, organic acids have a negligible effect on the differences in alkalinity generation in the upland soils of the two catchments.

After water leaves the soil horizons it enters the groundwater pool. The Plastic ground water pool size is very small relative to that of Harp. Consequently there are gross increases in alkalinity in Harp catchment as water passes through the groundwater pool (167 for Harp vs. 5 $ueq \cdot L^{-1}$ for Plastic). This is primarily the result of base cation release (246 vs. -5 $ueq \cdot L^{-1}$). The Plastic ground water also loses a small part of its high sulphate and aluminum load.

Stemflow (precipitation in contact with tree bark) was monitored at Harp and Plastic watersheds to determine the contribution by stemflow to the flux of ions to the soil/bedrock. This flux was compared to the contribution from incident precipitation and from throughfall (precipitation falling through the forest canopy).

Throughfall concentrations are related to atmospheric sources, canopy composition and dry deposition whereas stemflow is affected by both leaching of ions from the bark and washing off of dry deposits.

The forest cover at the Plastic Lake site is dominated by the conifers white pine and eastern hemlock while the forest cover at the Harp Lake site is dominated by deciduous species, soft maple and hard maple.

With minor variations due to differences in precipitation frequency and quantity in different years, it was determined that the conifer forest at Plastic Lake intercepted 78% of the incident precipitation. Most of this, 76%, was found as throughfall, with only 2% as stemflow. The Harp Lake forest intercepted 85% of the incident precipitation, 82% as throughfall and 3% as stemflow.

Data from February, 1983 to February, 1984, showed incident precipitation pH nearly identical at Plastic and Harp Lake sites, 4.27 and 4.21, respectively. However, upon interaction with the conifer forest, throughfall pH at Plastic Lake was reduced to 4.16, while at Harp Lake the pH increased to 4.33. This effect was even more pronounced in stemflow were the volume weighted average stemflow at Plastic Lake was pH 3.91, and at Harp Lake was pH 4.59. The neutralizing capability of conifer species is lower than the deciduous species.

The dominant anion in all solutions was sulphate. For the period discussed above, sulphate concentrations in incident precipitation at Plastic and Harp Lake sites were 54 and 61 $ueq \cdot L^{-1}$, respectively. Throughfall enrichment of sulphate at Plastic Lake resulted in a concentration of 103 $ueq \cdot L^{-1}$, while at Harp Lake this enrichment increased sulphate to

80 $ueq \cdot L^{-1}$. Stemflow enrichment resulted in sulphate concentrations of 260 and 200 $ueq \cdot L^{-1}$ at Plastic and Harp Lake, respectively. These differences may be due to the superior ability of conifers to intercept dry atmospheric sulphur compounds, as well as the presence of needles during the entire year.

The contribution of dry deposition is presented in an analysis of sulphate in precipitation events following dry weather of between 24 and 48 hours in duration and dry weather of greater than 120 hours in duration. Average throughfall concentrations at Plastic Lake were 100 and 120 $ueq \cdot L^{-1}$, for the two durations respectively.

The base cations calcium, magnesium and potassium were all markedly enriched in throughfall and even more so in stemflow. Sodium concentrations were only marginally enriched in throughfall and stemflow. Enhanced enrichment in base cations was observed in the spring and fall when cuticles were not fully developed or when foliage senescence permitted accelerated leaching of these bases.

Ammonium ions were marginally reduced in throughfall, but substantially reduced in stemflow. Nitrate was marginally enriched in throughfall under both forest types, but remained unchanged in stemflow at Harp Lake and greatly reduced in stemflow at Plastic Lake. Nitrogen compounds are conserved in the canopy and assimilated by the foliage or microflora on the tree.

While the volume of stemflow was small when compared to throughfall, the concentrations of most ions in stemflow was very high. The bulk of this enrichment is due to leaching from the bark of the trees. In stemflow, high loading of ions including hydrogen, occurs in a small area around the tree. This effects the properties of soil near the tree and the soil water composition.

B. PROCESS STUDIES

Bioaccumulation of Nutrients

Estimates of the standing crop and growth rates of all major tree species have been made in the upland forest ecosystem of the Harp and Plastic sites. These will be used to calculate the annual increment of base cations, nitrogen and sulphur.

Researchers will use these data to calculate the rate of proton production as a consequence of forest growth as well as the rate of base cation loss from soils.

Comparisons of standing crop measurements will be made between stands, and with other forest stands in different deposition zones. These estimates will be integrated with known nutrient requirements of major tree species and with soil content and availability of these nutrients.

The study results will ascertain the adequacy of current rates of nutrient uptake for maintaining normal forest productivity and possible effects of acid deposition on these rates. Results are expected in the fall of 1989.

Mineral Weathering Rates

The purpose of this study is to identify the important weathering reactions that occur within a catchment and estimate the whole catchment rate of these reactions. Plastic Lake catchment was selected as the primary study area.

The two dominant rock types in the catchment are granitic gnesis and amphibolite. The soils are made of quartz, plagioclase, K-feldspar and vermiculite.

The time-integrated rates of removal of the important bulk chemical constituents since the time of glaciation have been determined from the soils of the Plastic Lake watershed. The relative rate of removal of these constituents in kg/ha/yr decreases in the order silica > aluminum > sodium > potassium > calcium > iron > magnesium.

The essential mineralogy of the soils of the Plastic Lake watershed includes quartz (30%), plagioclase feldspar (30%), potassium feldspar (15%), vermiculite (12%), amphibole (10%), and goethite (3%). The rates of removal of the various chemical constituents have been recast into the essential mineralogy to determine mineralogical weathering rates. Plagioclase feldspar is the most important mineral neutralizing acid within the soils through mineral dissolution. This mineral accounts for 55% of the acid consumed and feldspars as a whole consume 75% of the total. The estimated dissolution rate of albite within the soils ($1.75 * 10^{-12}$ mol $(Si)/m^2/sec$) is approximately one order of magnitude less than experimentally derived rates.

The estimated present day chemical weathering rate for the Plastic Lake watershed is approximately 250% greater than that of the long-term rate. This 2.5-fold increase may be a result of the input of anthropogenic acids into the Plastic Lake watershed.

Another study was conducted to assess the relative importance of inorganic (hydrogen chloride, hydrogen fluoride) and organic (oxalic) acids to feldspar mineral weathering. After leaching minerals for approximately 72 days, the mineral surfaces were analysed using SIMS (Secondary Ion Mass Spectrometry). Both the hydrogen fluoride solution and the oxalic acid solution were shown to be strong complexers of aluminum.

When other minerals such as Bytownite (a more calcite plagioclase) were used, it was shown that the nature of the mineral itself was important in the way in which the species dissolved.

In another study, samples were collected from Plastic Lake and slices were taken from stones in the till. Depth profiles were made from naturally weathered feldspars and from exposed fresh feldspars as a control.

For weathered plagioclase, the surfaces are highly aluminous and contain large proportions of calcium which means that the plagioclase is amorphous and susceptible to cation exchange on the surface.

For vermiculite compositions, significant absorption/exchange of calcium is suggested at the surface.

Vermiculite and plagioclase make up 70 to 75% of all materials at Plastic Lake. These substances probably have an effect on the chemistry of the runoff of the Plastic Lake catchment.

The mineral weathering information will ultimately be incorporated in the models of long-term changes in stream chemistry to determine the rate of acidification in the aquatic systems in the Muskoka-Haliburton area.

Sulphur Adsorption Studies

Sulphate is important in terms of watershed acidification and many factors influence its adsorption and retention.

Soil samples were taken from Plastic Lake subcatchment 1 from the B horizon. Soils from this region are typically acidic podzols.

Results of the laboratory studies show that higher in the soil horizon, there is a larger proportion of adsorbed sulphate than lower in the horizon. For these upper regions, a decrease in acid loading could result in the soil being an additional source of sulphate. With increased deposition, additional adsorption is possible. These results are being used in a catchment sulphate adsorption model.

Groundwater Studies

Groundwater was surveyed at one of the catchments of Harp Lake.

A groundwater monitoring network consisting of water table wells and piezometers was installed in order to collect hydrologic and chemical information. Results demonstrate that the dominant geochemical process in the groundwater in this watershed is silicate weathering and that alkalinity generation occurs along with silicate weathering in the deep basal till.

AQUATIC EFFECTS STUDIES

Contact: W. Keller

A. CHEMICAL STUDIES

Calibrated Watersheds

a. Chemical Limnology

The Limnology Section of the Water Resources Branch has intensively monitored a set of 20 streams and 8 lakes in the Muskoka-Haliburton area (Figure 22). Data collected now cover periods of 7 to 13 years. Researchers use these data to measure the long-term effects of acid deposition and trace metal inputs on the chemistry and biology of the study lakes.

Figure 22. Location of the study area and regions (shaded) of high SO_2 and NO_x emissions.

In the past few years, the relative contribution of nitric acid to precipitation acidity in eastern Canada has increased. As a result, researchers have become concerned about the potential deleterious effects of nitrate deposition on terrestrial and aquatic ecosystems.

To gauge the extent of this impact, annual mass balances for nitrates and ammonium were calculated for several forested catchments and lakes in Ontario. The analysis of nitrogen retention suggests that nitrogen saturation of lakes and watersheds has not occurred at present nitrogen loadings in eastern Canada, although there may be exceptions in specific stream catchments.

Increased nitrate deposition will result, however, in higher concentrations of nitrate and greater acidity in stream and lake waters, while decreased deposition should result in increased alkalinities.

Another study analysed alkalinity decreases during snowmelt in 1984-86 for 15 headwater streams and lake outflows in three central Ontario catchments. These depressions were likely to be dominated by sulphate increases as the degree of stream acidification increased. Neither nitrate nor organic acid anions were significant contributors to alkalinity depressions.

The data collected from these studies will be used to determine target loadings for nitrogen and to refine the existing target for sulphur deposition.

b. Metal Contaminants

Surveys of contaminant levels in Ontario fish have shown widespread mercury contamination even in areas remote from local anthropogenic sources. Also, there appears to be a tendency for mercury levels in acidified lakes to exceed those in non-acidified lakes.

Currently, the source of this contamination is unknown. However, the widescale nature of the contamination suggests either geologic release of mercury to lakes is common or the atmosphere is dispersing and depositing mercury over much of the continent.

Studies are under way to identify the sources of mercury in sensitive areas and to determine the relationships between mercury concentrations in water and levels in biota.

Mercury in precipitation and in the major streams of a central Ontario lake (Harp Lake) has been measured over the past year. By coupling these measurements with precipitation depth and stream discharge information, scientists have estimated the amount of mercury supplied to the lake by streams and by precipitation. The study showed that volume weighted mercury concentration of precipitation was 10.2 $ng \cdot L^{-1}$ and was 3 to 6 times higher than streams. Direct wet deposition accounted for over half of the supply of mercury to the lake. Watersheds retained most of the mercury deposited on them.

This study implicates the atmosphere as the principal source of mercury to Ontario lakes and probably to the fish in those lakes. As a result, control and reduction of mercury emissions to the atmosphere must be addressed.

The anthropogenic acidity of atmospheric deposition has increased the export of aluminum, manganese and possibly trace metals (lead, copper, cadmium, zinc) from acidified catchments. A recent study documented the deposition of trace metals onto the Plastic Lake catchment and determined where in the catchment they were being transported.

Results showed that precipitation in the Muskoka-Haliburton area contained trace metals (median values were 0.08, 2.28, 1.1 and 3.7 $ug \cdot L^{-1}$ for cadmium, lead, copper and zinc respectively). A review of the concentration of these metals at various points in the watershed shows increased exports of cadmium and zinc from the mineral horizons of soils impacted by acidic deposition. Conversely, lead and copper were not exported from the upland soils.

c. Extensive Lakes Sampling

During 1988-89, several regional lake surveys were completed.

The Northeastern Region continued to monitor a large set of lakes to determine whether lake water chemistry in the Sudbury area has continued to respond to reduced emissions from the Inco and Falconbridge smelters.

The Northwestern Region surveyed over 100 lakes north of Ignace. The purpose of this survey was to fill in a large geographic area where little or no lake water chemistry data existed previously.

The Southeastern Region surveyed smaller lakes in the region to fill a gap in the database. Smaller lakes had not been adequately sampled, and many lakes were missing complete water chemistry.

Dorset research centre surveyed 150 "ultra-sensitive" lakes (alkalinity less than 35 $ueq \cdot L^{-1}$) which had been sampled in 1982 and 1983. The purpose of the survey was to determine whether there had been any detectable change in pH or alkalinity in low alkalinity lakes in central Ontario.

Missing watershed and lake area data for well over 1000 lakes were determined by digitizing topographic maps. These data will be used to estimate the number of lakes in each watershed in various acid sensitivity categories for estimations of the lake resources at risk.

The data base for Ontario now consists of partial chemical data of 6000 lakes, and relatively complete information on over 3300 lakes. In the southern and central parts of the province, this constitutes a significant proportion of the overall lake population.

The water chemistry in large areas of Northern Ontario remains unknown. However, these areas of the province receive little in the way of acid deposition, and although many of those lakes may have low acid neutralizing capacity, they are not in danger of acidification unless there are drastic increases in sulphur emissions.

A complete assessment and documentation of the data base (pH, alkalinity, variety of nutrients and some metals) is in preparation, and will provide an extensive synoptic look at the spatial patterns of water chemistry within the province.

B. BIOLOGICAL STUDIES

Lake pH - Algal Sediment Fossils

The "new" diatom taxonomy published recently by the U.S. based paleolimnology group PIRLA was applied to the 50 lake calibration set from Ontario. Some sections of cores from Hannah Lake and Clearwater Lake (Sudbury area) have been analysed as a test of the diatom calibration.

A first draft of the chrysophyte scale calibration (same 50 lake set) was also prepared. Cores from Plastic and Clear Lakes (Sherbourne Twp.) were analysed so that down-core histories of the same six lakes (Plastic, Clear, Maggie, Pincher, Lady, Raven) are available for both the diatom and chrysophyte scale calibration.

A third calibration was developed using chrysophyte cysts. About 130 different cyst morphotypes were used to develop calibration equations (r^2 greater than 0.9) on the same 50 lake set. Analyses of cysts in core sections from Plastic, Maggie and Lady have begun. The inferred pH history of these lakes will be available by all three techniques (diatoms, chrysophyte scales and chrysophyte cysts) by 1990.

Filamentous Algae

Spatial and temporal analysis of benthic algal populations in Swan Lake (Sudbury area) was used to determine changes in algal growth due to pH changes since 1981-82. There was a decrease in algal abundance in 1987 as pH increased, and an increase in abundance in 1988 as pH decreased. The seventh consecutive year of algal mapping was completed in Bowland Lake (whole-lake neutralization study), and Lake 302S (whole-lake acidification study). Increased growth of algae in Bowland Lake (which is now reacidifying), and Lake 302S, is also consistent with acidifying systems.

Filamentous algae in Plastic Lake were mapped for the eighth consecutive year. These data are used to evaluate seasonal and year

to year changes in algal growth. Plastic Lake also serves as a valuable reference to assist in the interpretation of algal growth on less intensively studied lakes. Aerial mapping of Lake of Bays was continued for the third consecutive year. Results showed that about 4 to 10% of the shoreline (mostly in the smaller bays) was covered with filamentous algal clouds during 1986-88. This may be an indication of early acidification stress.

Follow-up statistical analyses to the 1986 Cottager Questionnaire Survey related lake physical/ chemical characteristics to predicted algal status. Lake pH was one of several statistically significant variables that explained algal presence.

A final report was received on the taxonomy of Zygnemataceae in Ontario lakes. Results show an apparent pH preference associated with various species of filamentous algae.

Zooplankton

Several studies are underway to determine the effects of acidification on zooplankton in Precambrian Shield lakes.

To aid in understanding the mechanisms of the decline in richness and alterations in the structure of the zooplankton community of Plastic Lake, short term intensive studies were initiated. Studies included the impacts on zooplankton of predation by larval Chaoborus and fish, parasitism by microsporidia, and inter-and intra-specific competition.

The impact of acidification on Daphnia galeata mendotae Birge, a very common large cladoceran herbivore in lakes of eastern North America was investigated. Results from laboratory toxicity studies, in soft waters, demonstrated that this zooplankton species is highly acid sensitive. Observed distributions in 445 dilute Ontario lakes subjected to differing degrees of sulphur deposition and spanning a wide pH gradient, are consistent with laboratory studies, showing a substantial decline in the abundance of D.g. mendotae near pH 6.0. The close agreement between field and laboratory data indicate that widespread negative impacts on this important species have occurred due to acidification.

Investigations of the impacts of acidification on littoral microcrustacean communities have been initiated in collaboration with staff of the National Museum in Ottawa.

Temporal patterns in the species richness of crustacean zooplankton communities were assessed in eight Sudbury area lakes, based on data collected between 1973 and 1986. During this period, the study lakes showed general reductions in acidity and trace metal concentrations related to reduced contaminant emissions from the Sudbury smelters. Despite water quality improvements, several of the study lakes continue to have low pH (less than 5.5) and elevated trace metal concentrations which have inhibited recovery of zooplankton diversity. However, in lakes with current pH near 6.0 and low trace metal concentrations, substantial increases in average crustacean species richness have occurred.

Invertebrates

Scientists are comparing stream insect data collected 50 years ago from surveys of two low-alkalinity streams in Algonquin Provincial Park with data collected from recent surveys (1984-1986).

The same species were observed in 1984-86 as were observed 50 years ago in streams where pH shifts were small (6.4 to 5.7). But, at sites

where large pH decreases occur (6.4 to 4.9), many mayfly and stonefly species present 50 years ago had disappeared by 1984-86. We know that these insect species are sensitive to low pH. This loss of acid-sensitive species shows that poorly buffered surface waters have acidified somewhat over the past 50 years.

The effects of short-term pH depressions in spring on whole-body concentrations of nine metal cations (calcium, magnesium, sodium, zinc, lead, aluminum, manganese, cadmium and iron) and survival of two species (one mayfly species and one blackfly species) of aquatic insects collected from two habitats with year-round differences in pH were examined in a transplant experiment. Survival was close to 100% in 4 and 10 day in situ toxicity tests prior to and during snowmelt at pH levels ranging from 6.5 to 4.2.

Both species transplanted from pH 6.2 to 4.2 streamwater had significant decreases in whole-body concentrations of calcium, aluminum and manganese. Additionally, mayflies had significant losses of magnesium, iron and lead, while blackflies decreased in whole-body sodium and zinc concentrations at the low pH (4.2). The percent of aluminum adsorbed doubled in transplanted (versus control) mayflies, but the overall whole-body aluminum concentration decreased. Trends in the data support the hypothesis that adsorption of aluminum increases at lower pH levels.

Toxicity Testing

The absence of a species from a lake with low pH waters or even the observation of a population failure in an acidifying lake does not constitute proof that a species is adversely affected by acids. To establish a cause-effect relationship between an acid and the loss of a species, controlled laboratory toxicity studies must be conducted. These data along with population data provide evidence of the acid tolerance of a species.

Such studies may also provide information on the relative sensitivity of different species to acids, and they can be used to investigate the influence of other water quality factors on the sensitivity of biota to acids.

In the past, the emphasis in toxicity testing has been on sport fish, but survey data suggest that many of the small forage fish, in particular the cyprinids, are the most acid sensitive group of fish.

Consequently, recent toxicity work has focused on forage fish.

In 1988 creek chub, blacknose dace, Northern red belly dace, golden shiner, bluntnose minnow and fathead minnow at the embryo-larval stage (the most sensitive life stages) were tested for their acid sensitivity. Bluntnose minnow and creek chub were most sensitive with a 20 day LC50 of about pH 5.6. Golden shiners were most resistant, with a 20 day LC50 of about pH 4.6. Fathead minnow, blacknose dace and northern redbelly dace were intermediate in sensitivity. Essentially all of the mortality occurred during the embryo stage, and most of this in the first few days of exposure. Times to hatch were delayed slightly, but only near the LC50. Similar work will be conducted in 1989 in order to fill in some gaps in the 1988 data, and to extend the data set to include common shiner, rainbow smelt, and sculpins. Ultimately these data will be compared to survey data on the same species.

Acids exert their toxic effects by disrupting ion regulation, and it is known that high levels of metabolic ions (calcium, magnesium and sodium) in the water can reduce acid toxicity. However, there is little

work over the natural range of these ions in softwater lakes. Their significance for the survival of fishes subjected to acid stress is not clear, nevertheless, there are some indications that acids may be much more toxic in the most dilute waters of Precambrian Shield lakes compared with waters of higher ionic content.

To determine whether the ionic composition of lakes is a factor, the effect of varying calcium and sodium concentrations on the toxicity of acid to fathead minnows has been studied. Using specific ion concentrations, the results show that calcium and sodium decreased the toxicity of acid solutions anywhere between 0.1 and 0.4 pH units. More dilute combinations of calcium and sodium must still be tested.

Biological Survey

Historically, research has concentrated on the adverse effects of acidification on sport fish. Recently, the emphasis has shifted to more sensitive organisms, the benthic invertebrates. They form an important part of the diet for sport fish.

Biological surveys of softwater Shield lakes were designed to identify aquatic invertebrates that may be sensitive to low pH and to quantify their response to low pH.

Sampling of the littoral zone (shoreline) invertebrate community was completed on approximately 60 lakes during the fall of 1987. Concurrent water samples were taken for chemical analysis. Additional samples were collected in the fall of 1988 to augment the data on low alkalinity lakes. The biological samples are being processed to identify species to the lowest practical taxon. Statistical analyses of the chemical and biological data will determine any significant relationships between the chemical parameters and the occurrence of particular biota.

A report on this study will be available by the end of Fiscal Year 1989/90.

Biological Monitoring

The decline of a population of plants or animals in response to deterioration of water quality due to acidification is highly variable. It may be slow and barely perceptible over a span of a few years or it may be quite abrupt. The rate of population decline appears to be related to the normal lifespan of the species.

Because adult organisms tend to be more tolerant than young or newborn animals, long lived animals may persist years after they fail to reproduce. The persistence of adults and occasional successful recruitment prevents abrupt population failure. Many aquatic animals, however, live only one or two years and only breed once in their life. Because of these life cycle characteristics their populations can decline rapidly after recruitment failure, and in several instances local extinctions of snails and amphipods have been documented in acidifying lakes in the Muskoka-Haliburton area.

In 1988 the Biological Studies Unit of the Dorset Research Centre initiated a monitoring programme that focuses on short lived species. Although species with short life spans can be found within all major groups of animals, the greatest concentration of them is found among the benthos, the organisms living on the bottom of a lake amid the rocks, plants, and mud, and it is toward this group that the programme is directed.

The initial work emphasized evaluation of methods (spring vs. fall sampling, determination of the optimum number and location of traps

for crayfish) and site documentation (aerial photography).

These data are currently under analysis, but some of the preliminary results are quite interesting. Of the twelve lakes sampled, four of them contained Orconectes virilis, a species of crayfish which is known to be sensitive to acid conditions. The four lakes spanned a range of pH from slightly acid to circumneutral (around pH 6.5), and over this range there was a clear correlation of shell hardness with pH. Moreover, the animals caught in the most acid lake were all large adults; no young animals were caught. That is, it appears that crayfish in this lake are the remnants of a population on the verge of local extinction. Future results from this lake will be most interesting.

Cursory examination of the data for other littoral benthic organisms show that there is a huge difference between the number of organisms caught by the "kick and sweep" sampling method in the spring and fall. It appears that fall samples have at least 10 times the numbers of organisms as the spring samples, and clearly the fall is the best time to sample.

Similar monitoring activities were initiated by the Department of Fisheries and Oceans in other areas of Canada. The data from south-central Ontario will be integrated with the national database to examine regional and temporal trends in community composition.

Metal and Organic Residue Monitoring

a. Monitoring Mercury Levels in Yearling Yellow Perch

This program is in its eleventh year for lakes in Muskoka-Haliburton with fewer years of data in the Sudbury, Chapleau and Thunder Bay areas.

Using data collected over the period 1978-87, pH explained 64% of the variability in mercury in yearling yellow perch in 15 lakes in Muskoka-Haliburton. There were no trends in mercury levels in the perch over the ten year period (1978-1987) in any of the lakes.

b. Investigating Relationships Between Mercury in Sport Fish and Lakewater Quality

Data collected under the Contaminants in Sport Fish Program and the Acid Sensitivity Program were used to assess the relationship between lake water quality and mercury in sport fish. The focus to date has been on lake trout and smallmouth bass. These results were reported in the 1987/88 APIOS Annual Program Report.

Similar analyses are currently underway for walleye, pike and brook trout.

MNR Fish Studies

a. Occurrence of Cyprinids and Other Small Fish Species in Relation to pH in Ontario Lakes.

Data from 426 Ontario lakes were used to determine how fish species number was empirically related to lake area and pH. In lakes with pH greater than or equal to 6.0, the total number of species increased with lake area, whereas the number of cyprinid species was generally unrelated to lake size. Accordingly, the fraction of total species number comprised of cyprinid species decreased with increasing lake size. Taking the effects of lake size into account, total number of species, total number of cyprinid species, and cyprinid fraction decreased with pH below pH 6.0.

An augmented set of 488 lakes was used to evaluate the potential of the 13 most common small fish species as early indicators of

changes in the fish community due to acidification. The most promising species were: fathead minnow (*Pimephales promelas*), common shiner (*Notropis cornutus*), bluntnose minnow (*Pimephales notatus*), blacknose shiner (*Notropis heterolepis*), and slimy sculpin (*Cottus cognatus*) (Table 3, Figure 23).

b. Resurvey of Sudbury Lake Trout Lakes

A chemical survey was conducted in January 1987 to resample 106 lake trout lakes that were originally sampled in January 1980. Similar methods were used to collect for determination of pH, alkalinity and specific conductance. Substantial improvements were detected. The number of lakes classified as acid stressed (pH less than 5.5) dropped from 46 (43.2%) to 20 (18.9%) in 1987. Biological resurveying began in 1988 to examine changes in the fish communities in lakes with improved water quality. Twelve lakes have been resurveyed (initial surveys: 1982-1985) to date. An additional 24 lakes will be resurveyed in 1989.

Table 3: The 13 most common small fish species found in acid-sensitive lakes in Ontario listed by estimated pH threshold for extirpation (disappearance from a specific lake). Suitability as an indicator of early changes in the fish community due to acidification is also given.

Species	pH Threshold for Extirpation	Suitability as Indicator Species
Slimy Sculpin	5.8 - 6.4	FAIR - Restricted to Northwestern Ontario
Blacknose Shiner	5.8	FAIR - Low Occurrence
Fathead Minnow	5.5 - 5.8	GOOD
Common Shiner	5.4 - 5.8	GOOD - Restricted to South-central Ontario
Bluntnose Minnow	5.6	FAIR - Restricted to South-central Ontario
Iowa Darter	5.4	FAIR - Restricted to South-central Ontario
Finescale Dace	5.4	POOR
Brook Stickleback	5.1 - 5.3	POOR
Creek Chub	5.0 - 5.2	POOR
Pearl Dace	4.7 - 5.2	POOR - Possible Increase in Abundance
Lake Chub	4.7 - 5.1	POOR
Northern Redbelly Dace	5.0	POOR
Golden Shiner	4.7 - 4.9	POOR - Possible Increase in Abundance

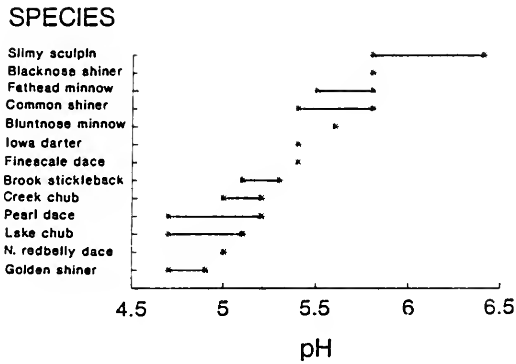


Figure 23. Estimated pH thresholds for extirpation for each of the 13 most common small fish species found in acid sensitive lakes. Ranges are shown when specific pH values could not be determined.

c. Long Term Monitoring in the Dorset Area

The trend-through-time monitoring program was amalgamated with the Muskoka Assessment Unit in Bracebridge. The baseline surveys that began in 1982 were completed on the original 12 lakes in 1988. Baseline studies on the additional "ultra-sensitive" lakes will be completed in 1989. Staff are now concentrating their efforts on data analysis and reporting. The results of these analyses will be used to design and schedule the next round of monitoring. Results will be available next year.

d. Smallmouth Bass Reproduction in Acidic Lakes

The effects of water quality in five acidic lakes on overwintering young-of-the-year and introduced adult smallmouth bass (Micropterus dolomieui) were determined in two separate experiments. Young-of-the-year (YOY) were held through the winter (November-April) in five lakes (mean winter pH 4.8 - 5.9) in the La Cloche Mountain area of Ontario. Survival declined with decreasing pH and increasing dissolved metal concentrations. Overwinter survival was 0% for YOY in Acid, Partridge and Terry lakes (pH 4.8 - 5.5; total aluminum 0.010 - 0.252 $mg \cdot L^{-1}$), but varied markedly (0 to 100%) in George (pH 5.8 - 5.9; total aluminum 0.050 - 0.062 $mg \cdot L^{-1}$) and A.Y. Jackson lakes (pH 5.8 - 5.9; total aluminum 0.028 - 0.041 $mg \cdot L^{-1}$) Wild adult bass from a number of circumneutral lakes in the Killarny area were transferred to four of the same lakes (A.Y. Jackson, Terry, Partridge, Acid) that were used in the YOY experiment. Survival estimates were obtained from snorkelling surveys during two spawning seasons (1987 and 1988). Adult survival was at least 55% (1987 and 1988) in A.Y. Jackson Lake (pH 6.1), at least 12.5% (1987) and 4.2% (1988) in Terry Lake (pH 5.3), and zero in Partridge (pH 5.1) and Acid (pH 4.8) lakes. Spawning was observed only in A.Y. Jackson Lake and subsequent survival of the early life stages was related to lake chemical conditions. A.Y. Jackson (pH range 5.7 - 6.4; total aluminum range 0.028 - 0.100 $mg \cdot L^{-1}$) was the only lake, of the five studied, with ambient water quality currently suitable for supporting a self-sustaining smallmouth bass population.

MNR Wildlife Studies

The Influence of Lake Acidification on the Reproductive Success of the Common Loon in Ontario

This is a joint project with the Long Point Bird Observatory.

The objectives of this study were to:

1) examine the mechanisms responsible for the effect of acidity on the reproductive success of the Common Loon and
2) identify how Common Loon reproductive performance and behaviour can be used to assess lake acidity.

A pilot project provided behavioral observations and prey sampling on 6 of 32 lakes originally surveyed in the Muskoka-Haliburton area of Ontario in 1988. Success rating of foraging dives appeared to be related to the type of prey utilized. In general, loons feeding their young primarily invertebrates had a success rate higher than that of loons on lakes where chicks were fed primarily fish.

Recommendations for further study include:

- an increased number of lakes to be surveyed
- observations throughout the breeding season (May to September) and increased prey sampling.

The Wildlife Toxicology Fund has recently approved funding for continuation of this study for 3 years, from 1989-90 to 1991-1992.

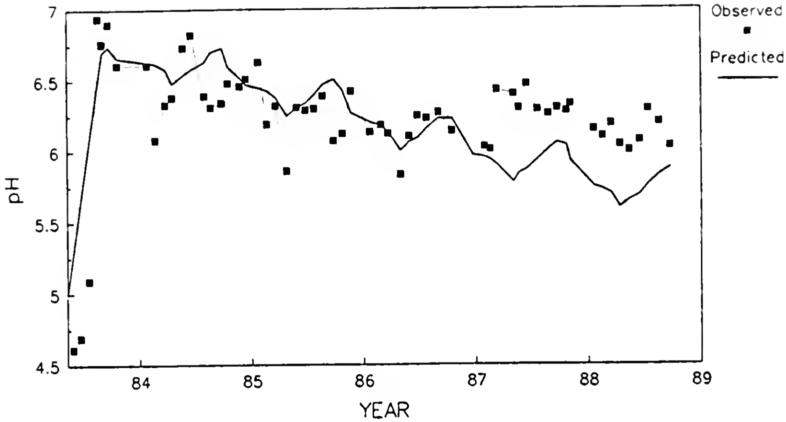
C. REMEDIAL METHODOLOGIES DEVELOPMENT

Bowland Lake

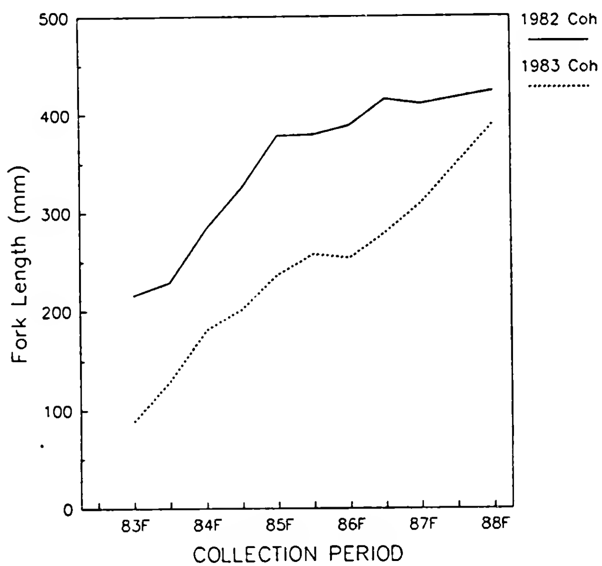
The lake was limed in 1983 with 84 tonnes of dry calcite. After liming the pH rose from 5 to 6.7, alkalinity increased from 0.3 to 4.5 mg$\cdot$L^{-1} and total aluminum dropped from greater than 130 to 30 ug$\cdot$L^{-1}. Models predicting lake reacidification have been compared to actual water chemistry in the six years since liming (Figure 24). Whole lake integrated samples for pH show higher than predicted values in later years, probably due to high algal production.

Lake trout stocked after liming are reproducing successfully, as three year old recruits have been captured. Lake trout growth is comparable to other lakes in the region. A perch population which had remained in the acidic lake, first increased following liming, then declined in numbers as competition and predation from lake trout increased with growth of the stocked trout (Figure 25). Lake trout eggs initially survived well in bioassays conducted on the near shore shoals after liming. In 1986 and 1988 however, survival declined in response to declining water quality during spring run-off and decreased whole lake buffering protection.

Benthic invertebrates exhibited shifts in biomass distribution among the major taxa in 1988 with Chaoborus almost disappearing from the hypolimnion. Crayfish numbers declined in 1988 although the incidence of softshell remained low.



<u>Figure 24</u>. Whole-lake and predicted pH for Bowland Lake, 1982-1988.



Hills L. and N. Bay 1982 cohorts grouped together.

Spring and Fall Periods

<u>Figure 25</u>. Growth of lake trout in Bowland Lake.

In contrast, littoral and planktonic invertebrates showed dramatic increases in abundance in 1988. These changes may be attributable to changes in predation pressures.

Prior to neutralization, greens and blue-greens dominated the phytoplankton community. In the last two years, there has been a decrease in the diatoms which increased after neutralization, with a subsequent increase in blue-greens possibly in response to changes in water chemistry.

Shoal Liming

Pilot scale shoals (3m x 6m) were built with gabion size calcite rubble in George and Johnnie Lakes in Killarney Provincial Park. Results from egg incubation experiments on these and Laundrie Lake (studied in 1985-87) show that calcite treated shoals definitely improve survival of lake trout eggs when mortality due to acidification is high (Figure 26).

Shoal liming is only useful, however, when whole lake water chemistry is of sufficient quality to allow the fry emerging from the protection of the shoals to grow into adult fish. This may be in a marginally acidic lake or in a neutralized lake both of which may require protection for lake trout embryos from acidic spring run-off.

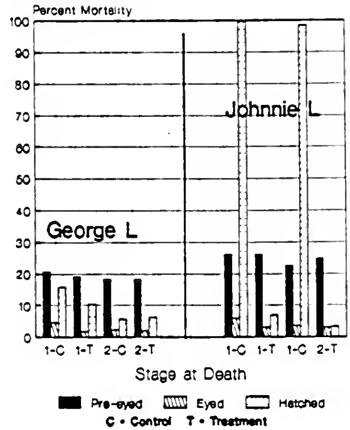


Figure 26. Egg mortality, 1987/88 over winter.

ENVIRONMENTAL MANAGEMENT AND ECONOMICS STUDIES

Contact: J. Donnan

A. DAMAGES AND BENEFITS

The focus of this work has been on ozone. Staff in Policy and Planning Branch and Air Resources Branch collaborated to generate estimates of the potential economic benefits to crop production of reducing ambient ozone concentrations. Health and materials effects were also examined.

B. COSTS OF ABATEMENT AND MITIGATION

Three investigations on the control of precursors to acid deposition and ozone formation were completed:

1. "Countdown Acid Rain: Future Abatement Strategies".

2. "Nitrogen Oxide and Volatile Organic Compounds Abatement Cost Study".

3. "Cost Effectiveness of Mobile-Source Pollution Control System".

The first study defined and evaluated options for further reductions in SO_2 and NO_x emissions assuming that Inco, Falconbridge, Ontario Hydro and the Algoma Steel iron sintering operation in Wawa are operating at their 1994 legal emission limits. Other sources are assumed to emit at their 1985 levels. This "status quo scenario" results in a total of 901,000 tonnes per year for SO_2 and 578,000 tonnes for NO_x as NO_2. Costs of emissions control from the sources were estimated for further reductions of 10, 30 and 50 percent beyond this status quo scenario.

The official SO_2 emission target for 1994 is 885,000 tonnes, or 16,000 tonnes below the "status quo" scenario used in the report. In practice, this difference will be absorbed by a combination of the four major sources emitting at a rate below their legal limits together with changes in emissions from other sources.

In addition, the magnitude and costs of abatement in other industrial sectors which would have to be made if one or two of the major sources were unable to implement their mandated reductions were also produced.

The numbers are intended to be indicative only, since they are based on a number of assumptions including the cost of types of abatement equipment chosen as surrogates for what might actually be used.

The study showed that Inco is the least-cost source for SO_2 control. If Inco failed to reduce any of its SO_2 emissions it would be difficult and exceedingly expensive to meet the provincial SO_2 emission objective even with all industrial sectors at maximum technologically feasible control (and without any plant closures).

If Ontario Hydro, the major stationary source of NO_x failed to reduce emissions below its 1985 levels, more stringent controls by mobile sources could compensate.

A 10% reduction below the 1994 SO_2 status quo scenario would cost about $159 million in present value terms while a 30% reduction would cost about $887 million or an additional $728 million. With a 50% reduction the price tag jumps to $5.338 billion. If Inco does not reduce its emissions below 1985 inventory levels, an expenditure of about $4.9 billion in present value terms would be required to reduce all other industrial sources to the maximum that is technologically feasible. Under this scenario, SO_2 emissions would still total 1,019,000 tonnes per annum, higher than the 901,000 tonne level assumed in the status quo scenario.

The second study listed, estimated the costs of achieving NO_x and Volatile Organic Compound (VOC) reductions at stationary sources in the Sarnia and the Hamilton-Toronto-Oshawa metropolitan regions. These pollutants are precursors to ozone formation. Stationary sources in the study region account for 42% of the total provincial inventoried NO_x emissions and 65% of the total provincial stationary source VOC emissions. Stationary sources, however, are responsible for only a portion of total NO_x emissions. Transportation NO_x, which was not covered by this study, accounted for 64% of total provincial NO_x in 1985.

Estimates of the capital and operating cost and their distribution among industries and control technologies were developed for three control scenarios:

- Lowest Achievable Emission Rate (LAER) at all sources without closing plants, irrespective of economic achievability.
- Specified minimum control level applied to all emission sources (i.e., equal percent reductions at each emitter, regardless of cost).
- Least-cost control to achieve successively lower levels of total emissions, from existing levels to LAER.

Costs were estimated at individual emission sources in each plant in the study region for which emission data were available. Cost estimates of NO_x abatement in the study on "future abatement strategies" were average costs of control applied to the total emissions in each industrial sector.

Table 4 shows that the LAER level of VOC control can reduce controllable point source emissions in the study area by as much as 84%, from 23,198 tonnes to 3,669 tonnes per year, at a cost of $22.4 million per year or $1,145 per tonne removed.

Table 4: VOC Abatement Scenarios Sarnia & Oshawa-Toronto-Hamilton Metro Areas

Scenario	Final Emissions (tonnes)	Annual Cost ($)
1985 Emissions from Controllable Sources	23,198	0
Min. 80% Reduction at Each Source	4,139	19,454,000
80% Reduction at Least Cost	4,711	15,555,000
LAER (84.2% Red.)	3,669	22,364,000

NB: Capital Costs annualized at 10%
Source: VHB Research & Consulting Inc., March 1989

Table 4 also shows that reducing all controllable sources of VOC's in the region by at least 80% would cost $19.5 million per year. However, a more selective application of emission targets at different sources could achieve a total 80% reduction of VOC emissions at a minimum total cost of $15.6 million per year.

Table 5 shows that the LAER level of abatement for NO_x from stationary sources in the study area would reduce controllable emissions by 55%, from 47,922 tonnes to 21,500 tonnes per year, at a cost of $320.0 million per year or $12,100 per tonne.

Furthermore, a minimum reduction of 40% could be achieved at all controllable NO_x sources in the study region at a cost of $61.9 million per year or $3,191 per tonne of NO_x removed. In contrast, abatement at the different stationary sources of NO_x considered in the area could be ranged so as to achieve a 40% reduction in total emissions at a cost of only $50.0 million per year.

The report also identifies the cost of specific VOC and NO_x abatement technologies identified as "proven" for this study under the different scenarios.

The study clearly shows that efficient abatement programs can be designed but that all sources would not have to reduce their emissions by the same degree under these programs. A scenario that appears to be more "equitable", in that each emitter will have to reduce by the same degree will be more costly to achieve.

Control of VOC emitters from stationary sources is much more cost-effective than control of NO_x emissions (i.e., a lower cost per tonne removed). This means that VOC

Table 5: NO_x Abatement Scenarios Sarnia & Oshawa-Toronto-Hamilton Metro Areas

Scenario	Final Emissions (tonnes)	Annual Cost ($)
1985 Emissions from Controllable Sources	47,922	0
Min. 40% Reduction at Each Source	28,539	61,864,000
40% Reduction at Least Cost	28,753	49,996,500
LAER (55.1% Red.)	21,500	319,974,500

NB: Capital Costs annualized at 10%
Source: VHB Research & Consulting Inc., March 1989

emissions should be reduced before NO_x on a cost basis unless there is evidence that relative degree of environment risk or harm attributable to NO_x is greater than for VOC. The Atmospheric Processes Studies section addresses this issue.

The third study was intended to evaluate the cost effectiveness of vehicle emission control in Ontario and to assemble data on the populations of motor vehicles and other mobile sources of air pollutants.

The study found that about 5 million cars and light duty trucks and 73,000 heavy duty vehicles are currently operating in Ontario. Emissions of NO_x, CO and hydrocarbons (VOC's) were estimated for these vehicles and for other mobile sources including aircraft, railways, ships, household engines, pleasure boats, and farm equipment.

Passenger cars and light duty trucks constitute the largest vehicle population and are the primary sources of pollutants. The study identified "Cases" or control scenarios for passenger cars: Case A assumes that new emission standards promulgated in 1987 by the federal government would continue. Case B assumes that three-way catalytic converters, capable of meeting a NO_x emission standard of 0.4 gm/mile, plus pre-heaters and warm-up catalytic converts are required on all new cars, and thus a greater degree of emission control could be achieved from vehicles.

Preliminary estimates from the report indicate that the marginal cost of NO_x removal by adding three-way catalytic converters to new vehicles would amount to $1,777 per tonne of NO_x removed (Case A to B). The marginal cost attributed to moving from Case A to Case B for CO control ranged from $709 to $940 per tonne of CO removed while hydrocarbon removal would cost between $614 and $11,606 per tonne removed, depending on the apportionment of joint costs to each pollutant.

These studies indicate that NO_x control at mobile sources appears to be much more cost effective than at stationary sources.

LABORATORY SUPPORT SERVICES AND METHODOLOGY STUDIES

Contact: F. Tomassini

The Laboratory Services Branch provided analytical support to the scientific work groups within APIOS. A summary of the total test load for the program is shown in Figure 27. The largest increases in work were associated with analysis of trace organics in precipitation (17,500 tests) and vegetation analyses under the Maple dieback study (17,200 tests). The final total tests load for the program in 1988/89 was 357,800, an increase of 13.8% over the 1987/88 fiscal year.

Highlights for 1988/89

A new Varian AA400P atomic absorption spectrometer was purchased. If results are acceptable, the new instrument will be used to analyse both precipitation and surface water samples from the APIOS programs. Currently there are two older instruments providing this service.

The data transfer routine via modem from Dorset to Toronto was successfully completed during the year. All LIS information from Dorset to Toronto is now updated twice weekly without the need for shipment of tapes. Full implementation of a new coding method (bar coding) for samples and submission information in Dorset is expected in the next year.

Both the Toronto and Dorset laboratories continued to analyze samples submitted under an inter-comparison study spearheaded by the Federal laboratory in Burlington. A total of 54 laboratories from across North America are involved. Samples are submitted approximately 3 to 4 times a year. Twenty different sets of samples have been analyzed to date. During 1988/89 our laboratories participated in four of these inter-comparisons. Performance for both Toronto and Dorset laboratories was satisfactory. The average per cent Bias for the sample analysis on our data was 21.9. In many instances the magnitude of the bias for the Toronto laboratory was minor and insignificant for the demands of the data user i.e. less than 1% of full scale for the test. Dorset was one of only five laboratories of the total of 54 to achieve a score of 0 in LRTAP inter-comparison #19. In these studies a score of less than 10% is considered well done, 10-25% is satisfactory, 25-60% is moderate and greater than 60% is poor.

Method development is ongoing. The dependence of extractable iron and aluminum on soil particle size was investigated. Installation of a total carbon furnace attachment for the carbonate carbon analyzer was successfully completed. A comparison study between an automated method for colour measurement and the manual Klett-Summerson method was carried out. Comparisons between GFAAS and ASV methods for cadmium analysis, and comparisons between undigested and UV digested samples for cadmium continued.

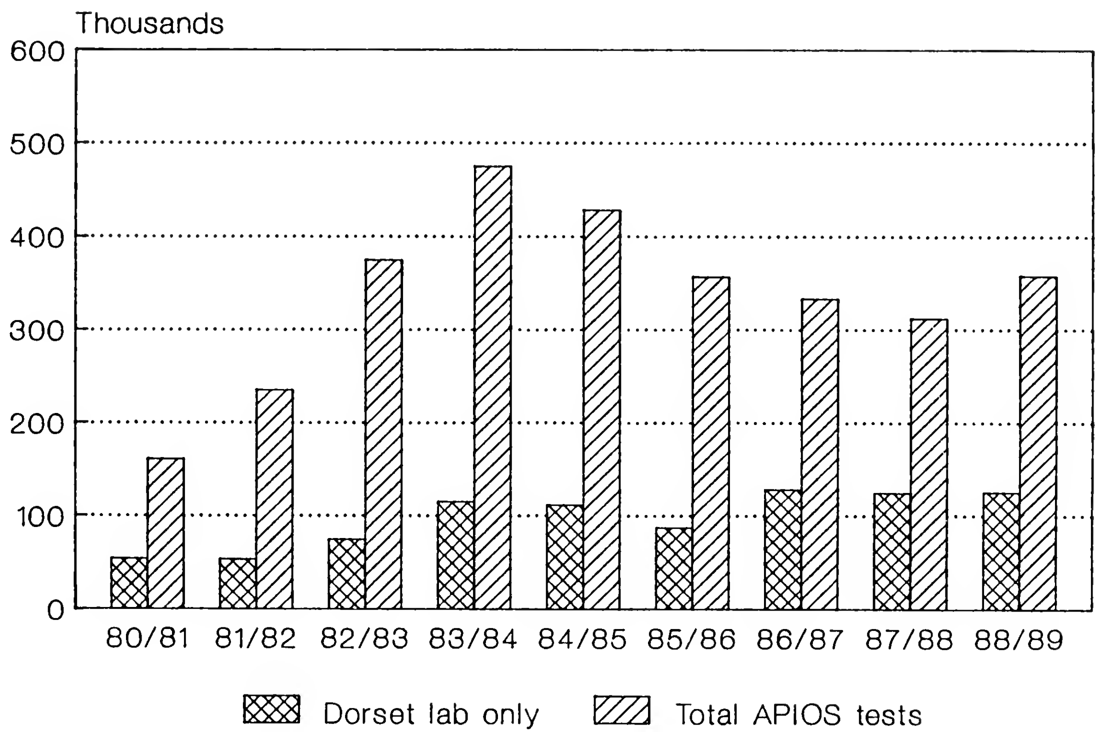


Figure 27. Laboratory Workload Summary

ABATEMENT

Contact: G. Endicott

Since 1980, Ontario has been convinced that sufficient evidence existed to implement immediate SO_2 controls while research continued to evaluate the benefits of these controls. As a result, Ontario was the first jurisdiction in North America to mandate emission controls based solely on the effects of long-range transport of air pollutants, as distinct from local ambient air quality standards. Ontario Hydro and Inco were the targets of these controls.

In the absence of an acid rain agreement with the United States, the federal government and the seven Canadian provinces east of Saskatchewan decided in March 1984, to take unilateral action and reduce their sulphur dioxide emissions to a ceiling of 2.3 million tonnes by 1994, a 50% reduction from the 1980 base case value. On February 5, 1985, they agreed to the series of steps to achieve the first 1.9 million tonnes of this reduction and committed to determining the allocation of any further reductions in sufficient time to achieve the 1994 objective.

Subsequently, Ontario went beyond the commitment it made at the federal/provincial meetings with its announcement of the Countdown Acid Rain program in December, 1985. Ontario will reduce sulphur dioxide emissions from the 1980 base case level of 2,194 kilotonnes to 885 kilotonnes by 1994.

Four non-appealable regulations were issued to the four corporate sources which together emit 80% of Ontario's SO_2: Inco, Falconbridge, Algoma Steel (Wawa) and Ontario Hydro. The regulated annual emission limits were developed in consultation with each of the major pollution sources to ensure that economic activity need not be excessively inhibited.

A phase-in approach is taken. Regulated limits are summarized below (Table 6).

Table 6: Legal Limits for SO_2 for the four companies

Source	Legal Limits Sulphur Dioxide 1986	1994
	(thousands of metric tonnes per year)	
Inco, Sudbury	685	265
Falconbridge, Sudbury	154	100
Algoma, Wawa	180	125
Ontario Hydro, province-wide	370	175

A fifth regulation limits SO_2 emissions from new or modified boilers by placing a 1 per cent sulphur content constraint on the fuel or by requiring that an equivalent amount of SO_2 be removed from the flue gas.

In addition to the SO_2 limit, the sum of SO_2 and NO emissions is also regulated for Ontario Hydro.

Furthermore, there are interim limits by 1990 (Table 7).

Table 7: Ontario Hydro's Acid Gas Limits

	SO_2	SO_2 + NO
	(Kilotonnes/Yr)	
1986-1989	370	430
1990-1993	240	280
1994 +	175	215

Control technologies were not specified so that the individual companies may choose their method of abatement. The regulations only require that the legal limits are met by the specified dates. The regulations provide for a three year research and development period. Semi-annual interim progress reports are required from the four major companies, and they are reviewed by experts from various Ontario ministries. A final report was received on December 31, 1988 from each of the metallurgical companies and in January, 1989 from Ontario Hydro. These reports clearly stated that the companies would be able to meet the regulated limits, and the reports described precisely how the emission limits would be met. The government's summary and analysis of all these reports along with copies of the company reports are available upon request.

Countdown Acid Rain will do more than just help Ontario's environment; it will also reduce acid rain in Quebec and the northeastern United States. However, the major emission reductions in Ontario and elsewhere in eastern Canada will not be sufficient to protect the environment. Major emission reductions are also required in the United States.

All Canadian attempts to negotiate a bilateral treaty on acid rain with the United States failed during the Reagan Administration. While President Reagan reaffirmed his commitment to clean coal technology development and agreed to consider the possibility of an accord, there had been no significant progress made.

President Bush has committed to a Bill to control acid rain. The proposed Bush Bill was announced on June 12, 1989 and details given on July 21, 1989. In essence, the Bill calls for a two-phase reduction of SO_2; 5 million tons (including a 1 million ton reduction which has already occurred) by 1995 and another 5 million tons by 2000 with respect to the 1980 base case. A reduction of 2 million tons of NO_x is also proposed in the Administration Bill. There are provisions for utility and pollutant trading and an extension to the year 2003 if clean coal technology is employed in the repowering.

The proposed Bill is clearly a step forward. Timing for signing legislation is uncertain as debates and changes made to the Bill are expected at Congress.

In addition to the domestic Bill, a U.S.-Canada accord on acid rain will also be developed.

COMMUNICATIONS INITIATIVES

Contact: G. Merchant

The Communications Work Group (with representatives from the Ministries of Intergovernmental Affairs, Tourism and Recreation, and Natural Resources), discussed and implemented strategies to increase awareness of acid rain among Ontario and American citizens.

ONTARIO

Ontario citizens are aware of acid rain as evidenced by the number of information requests made directly to the APIOS Coordination Office. 587 individualized packages of information were mailed in this fiscal year and about 500 people visited the Office. As well, there were numerous presentations to schools and interest groups. These contacts are over and above the enormous quantity of requests for acid rain information and the fish poster handled directly by the Communications Branch. In total, approximately 260,000 brochures and posters were sent to Canadian and American citizens.

UNITED STATES

The communications strategy directed toward targeted U.S. audiences stresses several themes:

° Human Health - Evidence has been accumulating that acid gas emissions are detrimental to human health.

° Out of the Trenches - Instead of focussing on the stalemate between those in the northeastern and midwestern states, people in other regions of the U.S. are being made aware of their stake in the issue.

° Effective American Legislation Is Required - There is a need for an interim and longer-term cap on acid gas emissions to prevent back-sliding and reach a scientifically supportable critical loading.

- The sooner the better. Biological systems tolerate considerable stress before suddenly crashing.

° It Can Be Done - Cost-effective acid rain abatement technology options do exist. There are specific economic benefits of abatement in the creation of a strong environmental protection industry.

- Ontario's <u>Countdown Acid Rain</u> program serves as a model of a successful abatement program.

This approach is intended to increase Americans' awareness of acid rain and of the solutions that do exist. To this end, several initiatives were undertaken and included the following:

Ontario was the lead agency in organizing three acid rain information trips to Canada for a

total of 17 congressional legislative assistants. These included visits to Toronto, the Dorset research centre, Sudbury, Ottawa and Quebec. Meetings were held with federal and provincial political leaders, the Canadian Coalition on Acid Rain, and executives from Inco, Ontario Hydro and Falconbridge.

A similar information trip was conducted for seven U.S. journalists in July.

A pamphlet entitled "It Falls On All Of Us" was developed to present key statements on acid rain. It proved to be popular and more than 140,000 copies were distributed to the American public.

The Ministry of the Environment and Trout Unlimited jointly organized a mail-out of Ontario and federal government acid rain information pamphlets to Trout Unlimited members (43,000). The mail out was arranged for July 1988. Trout Unlimited has reported that it will continue to prompt its members to write their government representatives as new acid rain control bills enter Congress. This joint program evolved from a contact made at Trout Unlimited's 28th National Convention (August 1987), attended by APIOS representatives.

Similar to previous years, an acid rain display was exhibited and staffed by Ministry personnel at several international conferences and shows: The Air Pollution Control Association's annual conference in Dallas, Texas; The Arizona Commission On The Environment's annual conference in Prescott; Canada Day at the State University of New York in Plattsburgh; and the Cincinatti Sport, Boat and Camp Show. The display was well-received at all four shows and many valuable contacts were made.

In December 1988, staff from APIOS, Communications, Legal Services and the Minister's Office attended a Bi-National meeting on opportunities for controlling acid rain. Minister Bradley delivered the keynote speech which was the winner of an Ontario Information Officers FORUM award.

In February 1989, the Minister delivered a speech on the health effects of acid rain to the National Issues Conference at Marshall University, Charleston, West Virginia. A similar speech was given to over 17 different media representatives at the National Press Club in Washington, D.C. The speech was subsequently aired three times over The C-Span network -- the internal broadcast network which services all members of Congress. After the speech, the Minister and representatives from APIOS, Communications and the Canadian Embassy attended separate meetings with six senators and the new EPA director.

The Ministry of the Environment participated in the Harrisburg Pennsylvania Sportsman Show in collaboration with the Alliance for Acid Rain Monitoring (ALLARM), a Pennsylvania-based volunteer organization. The MOE rented exhibit space and provided ALLARM with some publications. ALLARM provided their exhibit and staff.

For the second and final year, a tear-off card requesting information on acid rain was provided with the application form for all non-resident angling licenses. In 1987, 10,000 requests were received out of 300,000 licenses issued. In 1988, 5,679 requests were received out of approximately 300,000 licenses issued. This drop in the number of requests is probably attributable to a lack of requests for updated acid rain information by anglers who received our information the year before.

LEGAL INITIATIVES

Contact: B. Carr

Under the Memorandum of Intent signed in 1980, Canada and the United States agreed to enforce existing laws and regulations responsive to the problems of transboundary air pollution. Since 1981, however, the Unites States Environmental Protection Agency has proposed the approval of revisions in State Implementation Plans (S.I.P.'s) under section 110 of the U.S. Clean Air Act which would lead to increases in allowable sulphur dioxide emissions from coal-fired power plants. Because increased emissions could affect the province's environmental quality, Ontario encouraged the U.S. EPA Administrator and state governments to disapprove any S.I.P. revisions which would result in any increase in permissible emissions of SO_2 in the U.S.

Seeking an avenue to effective acid rain controls in the U.S., Ontario has appeared at numerous hearings and participated in judical proceedings since 1981. These efforts have been made in conjunction with several American states, environmental interest groups, and citizens, and are directed at two key parts of the Unites States Clean Air Act: sections 115 and 126.

Section 126 provides for the intervention of the EPA's Administrator in instances when interstate air pollution can be shown to be preventing the attainment of national abatement air quality standards, or interfering with those prevention of significant deterioration or visibility measures which the Act requires to be included as a part of a state implementation plan. This path to acid rain controls was blocked in March 1989, when the U.S. Supreme Court said it would not hear an appeal by a group of northeastern states. This decision means that an earlier ruling by the U.S. Circuit Court of Appeals will stand. That court ruled the EPA was not required to force reductions of pollution originating in other states since the northeastern states did not adequately support their claims of injury.

Ontario has been more actively involved in proceedings dealing with the internationally-oriented section 115. This section provides, in pertinent part:

(a) Whenever the (EPA) Administrator, upon receipt of reports, surveys or studies from any duly constituted international Agency has reason to believe that any air pollutant or pollutants emitted in the United States cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare in a foreign country ... the Administrator shall give formal notification thereof to the Governor of the state in which such emissions originate.

Under section 115 the Administrator also has to make findings that the foreign country offers reciprocal rights to the United States and that the environment of the foreign country is endangered.

In April 1988, Ontario and a group of states filed independent petitions to the U.S. EPA Administrator requesting that he reaffirm findings of endangerment and reciprocity under section 115 which had been made informally in 1981 by the Administrator of the EPA and accepted in previous court actions, by publishing the findings in the Federal Register and then promulgating the findings as final rules.

In October, 1988 the Acting Assistant Administrator of EPA's Air and Radiation Office issued a response stating that it would be premature for EPA to take any rule making action until NAPAP findings are available for assessment in 1990.

In November 1988, a follow-up legal petition was submitted to the U.S. Circuit Court of Appeals for the District of Columbia by Ontario to require the U.S. EPA to formally make the findings of reciprocity and endangerment. The suit was joined by two U.S. environmental groups, the Sierra Club Legal Defence Fund and the Izaak Walton League of America.

Later, the Federal Government, Quebec, New Brunswick, and other Canadian environmental groups requested to become Amici Curiae (friends of the court) in support of Ontario.

Also in November, 1988, nine states (6 New England states, plus New York, New Jersey and Minnesota) also filed a parallel lawsuit against the U.S. EPA to force the agency to take similar action under section 115. This was joined by the National Audubon Society. Once formal findings are made the EPA is then required to compel states from which offending emissions come to reduce their emissions.

APPENDIX I

INTERNATIONAL LRTAP PROJECTS - MOE CO-FUNDING

Project Title	Funding Agencies	Purpose
Acid Deposition and Oxidants Model (ADOM)	Environment Ontario Atmospheric Environment Service Umweltbundesamt (West Germany) Environment Quebec State of Minnesota State of New York Electric Power Research Institute	To improve predictions of source/receptor relationships, through the use of eulerian concepts.
Bilateral Hardwood Decline Study	Environment Ontario Ministry of Natural Resources Environment Canada Department of Natural Resources - New Brunswick Ministry of Energy and Resources - Quebec Northeast Forest Cooperative	A study of the etiology of sugar maple decline across northeastern North America using a common methodology.
Eulerian Model Field Verification	Environment Ontario Environment Canada U.S. E.P.A. Electric Power Research Institute	A study design has been prepared for the field verification of the eulerian model.

Project Title	Funding Agencies	Purpose
Reversing Acidification in Norway - NIVA	Environment Ontario Norway Sweden Environment Canada United Kingdom	To test hypotheses on watershed sensitivity and to measure watershed response to reductions and increases in acid loadings. This issue has been recently raised by the U.S. E.P.A. as an impediment to designing a control program.
Unified Acid Deposition Data Base for Eastern North America	Environment Ontario Environment Canada National Atmospheric Deposition Program, U.S. Geological Survey Battelle Pacific Northwest Laboratory, U.S.	The unified data base should be useful for mathematical model evaluation and historical trend analysis.

INTERNATIONAL LRTAP PROJECTS - MOE PARTICIPATION

Project Title	Participating Agencies	Purpose
BACG (Bilateral Advisory Consultative Group)	Environment Ontario Ministry of Energy Ministry of External Affairs Environment Quebec Environment Canada Office of the President Department of State, U.S. Department of Energy, U.S. U.S. EPA National Acidic Precipitation Assessment Program	To respond to or implement recommendations of the Special Envoys' Report
Fisheries Loss Assessment Program	NAPAP Environment Ontario Ontario Ministry of Natural Resources EPRI Environment Canada	To assist NAPAP in the design of a program to assess fisheries loss in the U.S. related to acidic deposition.
Informal Calibrated Watershed Modelling Group	Environment Ontario Environment Canada United States Norway Sweden	To compare results and ideas on watershed studies. The work defines effects of acid rain and develops target loadings to prevent damage.

Project Title	Participating Agencies	Purpose
Interlaboratory Quality Assurance	Government and private laboratories in Canada and the U.S. (over 50 labs involved, including MOE)	To ensure the validity and compatibility of all data collected under LRT programs in North America.
Lake Acidification Mitigation Program	EPRI Clarkson College Environment Ontario	MOE has been requested to provide advice and information concerning lake liming projects.
National Acidic Precipitation Assessment Program Review	Environment Ontario Environment Canada Fisheries and Oceans Canadian Forestry Service Government and private laboratories in U.S.	Review of NAPAP interim assessment document findings.
National Surface Water Survey	EPA Environment Ontario Environment Canada	To characterize current water chemistry of lakes and streams in five U.S. Regions. MOE has been requested to assist in the development of the survey design.
Ontario/Germany Memorandum of Understanding	Ontario Federal Republic of Germany	To exchange information, scientists and modelling results to ensure that similar methodologies are used so that final results may be compared.

Project Title	Participating Agencies	Purpose
Ontario/Michigan Memorandum of Understanding	Ontario Michigan	To exchange information and perform joint studies to achieve and maintain a quality of environment to protect human health and the ecosystem where activities of one jurisdiction may affect the environment of the other.
Ontario/Minnesota Memorandum of Understanding	Ontario Minnesota	To exchange information on acid rain; to cooperate on specific projects (atmospheric modelling, RAIN - NIVA, aquatic effects in a medium deposition area).
Ontario/New York Memorandum of Understanding	Ontario New York	To exchange information on acid rain to improve understanding of acidification of the environment and establish coordinated courses of action in order to encourage abatement measures on an international basis.
Ontario/China Memorandum of Understanding	Ontario China	To exchange acid rain/LRT information, to develop and collaborate on acid rain/LRT projects, and to provide training for scientists through projects participation.

Project Title	Participating Agencies	Purpose
Ontario/NADP Intercomparison Study - Ely, Minnesota	Ontario National Atmospheric Deposition Program	To improve comparability of data.

APPENDIX II

APIOS RELATED TECHNICAL REPORTS AND SUBMISSIONS

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